Reports

Botanical and Geological Significance of Potassium-Argon Dates from the Juan Fernández Islands

Abstract. *Potassium-argon dating of five basalts from the three main islands of the Juan Fernández (or Robinson Crusoe) Islands of Chile in the southeastern Pacific gives ages of 1.01 ± 0.12 and 2.44 ± 0.14 million years for Masafuera, 3.79 ± 0.20 and 4.23 ± 0.16 for Masatierra, and 5.8 ± 2.1 for Santa Clara. These ages are much younger than that of the underlying oceanic plate and are consistent with the origin of the island-seamount chain from a mantle hot spot beneath the eastward moving Nazca plate. The young age for the archipelago suggests that speciation within endemic genera has occurred within the past 4 to 5 million years. Endemic genera of apparently more ancient origins, such as* Lactoris *and* Thyrsopteris, *have apparently dispersed to the islands and survive refugially.*

The Juan Fernández Islands (or Robinson Crusoe Islands) of Chile, located in the southeast Pacific, are famous as the site of the adventures of Alexander Selkirk who inspired the Robinson Crusoe character (*1*). There are three principal islands, all of volcanic origin (*2*): Masatierra (~18.5 by 5.5 km) and its small western neighbor Santa Clara lie about 660 km west of continental Chile; Masafuera (~8 by 5.5 km) is 150 km farther west (Fig. 1). The islands and several submerged seamounts near 33°S are on a nearly east-west trending aseismic ridge of elevated ocean floor. The Juan Fernández Ridge does not appear to be related to other features of the Nazca plate ocean floor, and it has been suggested that the islands are the products of isolated intraplate volcanism (*4*), perhaps associated with a hot spot.

The archipelago has 150 native species of flowering plants, 69 percent of which are endemic (*5*), including the monotypic family Lactoridaceae. The flora has been extensively described by Skottsberg and his co-workers (*5–9*). For our investigation of the patterns of phylogeny and the modes of speciation in the endemic taxa, it was necessary first to determine the ages of the islands.

Brüggen (*10*) had suggested an Eocene age for the hypothetical Sierra de Juan Fernández Ridge, which presumably extended from continental Chile out to the islands. The archipelago was thought to have formed by more recent volcanic activity, and subsequent subsidence of the ridge left the islands isolated by water. This was the geologic perspective that Skottsberg (*5*) used in explaining the presence of distinct endemic genera with apparent ancient affinities (such as *Lactoris*). The ocean floor in the vicinity is of Eocene age (*11*). Baker (*12*) concluded that the landforms indicated a late Tertiary age and potassium-argon dating of a sample of dolerite gave an age of approximately 5 million years (m.y.) for Masatierra (*13*). Baker later cautioned that the age was in doubt (*14*) and more recently (*4*) suggested that the morphology of Masafuera indicated an age of less than 1 m.y.

The rocks of the islands are principally basaltic but range in composition from highly nepheline normative alkali basalts to quartz tholeiites (*4*). Chemical and isotopic compositions are similar to the lavas characteristic of oceanic islands such as the Galápagos (*4, 11, 15, 16*). Pilger and Handschumacher (*17*) suggested that the Juan Fernández island-seamount chain, like other Pacific chains, may have been formed by a fixed hot spot or by another mechanism such as a propagating intraplate fracture. The ages of formation of the islands are important in evaluating the origin of these oceanic islands.

Five rock samples collected from the three major islands during a cooperative U.S.-Chilean expedition to the islands in 1980 were dated (Table 1). All the rocks analyzed were holocrystalline, porphyritic basalts and, except for sample 4, show only minor alteration (*18*). The dates are internally consistent. The two samples from Masatierra are analytically indistinguishable. The date for the Santa Clara sample has a large uncertainty because of large atmospheric ^{40}Ar corrections but is consistent with the Masatierra dates. Santa Clara is more highly eroded and probably was connected at one time to Masatierra. All these dates are consistent with an age of about 4.0 m.y. The Masafuera basalts are distinctly younger and are distinct from one another. Apparently volcanic activity on Masafuera continued for about 1 m.y.

The Masatierra dates are consistent with the dolerite date of approximately 5 m.y. cited by Baker (*4*) and suggest that igneous activity on Masatierra also continued for about 1 m.y. The age data are too sparse to define the duration of volcanism on the various islands, but this estimate of the time for building an island is similar to that proposed for several islands of the Hawaiian-Emperor chain (*19*). The ages are also consistent with the geomorphology of the islands: Masatierra is more eroded and has broader valleys, and Masafuera is more dome-shaped and has deep ravines. Although much older rocks that were submerged isostatically might underlie those that were dated, there is no evidence of this.

The hypothesis of linear ocean island

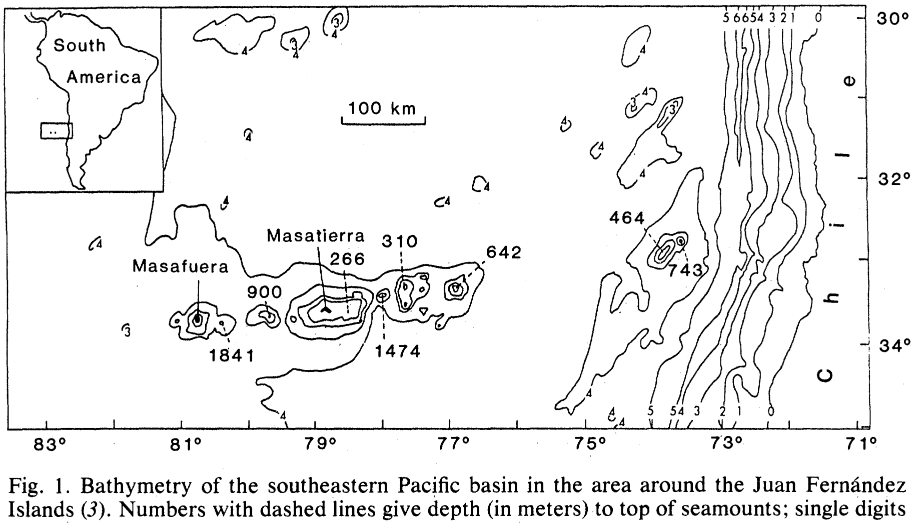

Fig. 1. Bathymetry of the southeastern Pacific basin in the area around the Juan Fernández Islands (*3*). Numbers with dashed lines give depth (in meters) to top of seamounts; single digits on contours indicate depths in thousands of meters.

chains originating from a fixed hot spot (*20, 21*) has been suggested for the Juan Fernández archipelago. Wilson (*21*) recognized this linear chain with ages in appropriate relative order as a potential hot-spot trace. The orientation of the Juan Fernandez chain is consistent, within the resolution of models for absolute plate motions (*22*), with the sense of motion of the Nazca plate over a southeast Pacific hot spot (*17, 23*), and the K-Ar dates are consistent, to a first approximation, with a fixed hot spot. Since the Nazca plate is moving due east at about 8.8 cm per year (*23*), Masatierra, about 150 km east of Masafuera, should be about 1.7 m.y. older than Masafuera. The differences in average ages of the two islands (Table 1) suggest that the hotspot hypothesis merits serious consideration. The age data, however, do not rule out other models proposed for Pacific aseismic ridges (*24*).

Bathymetric data (Fig. 1) show seamounts to the east of the present islands, although most are deep beneath the surface of the ocean, and only one extends far toward the continent. The most eastern seamount, assuming a constant rate of plate motion, would be about 11 m.y. old, but thermal models and subsidence of hot-spot swells (*25*) make it unlikely that this island would have been above sea level when Masatierra appeared about 4 m.y. ago. Although one seamount (310 m beneath the sea and estimated to be about 6 m.y. old) might have been available for colonization then, it would not have provided a land connection or a much closer stepping stone for the migration and establishment of the flora. At best, it would only extend the age of the archipelago to 6 m.y.

There are several important implications for the origin and evolution of the native flora. First, because the entire flora has developed within the last 4 to 5 m.y., there is a time reference for the origin of the 100 endemic species of angiosperms, which evolved from colonizers from continental South America or elsewhere. For example, 11 species in *Dendroseris* (Compositae) have evolved on Masatierra and three on Masafuera. Second, the endemic species on Masafuera are usually closely related to endemic congeners on Masatierra from which they were presumably derived during the past 1 to 2 m.y. Examples of this pattern are in *Dendroseris* (Compositae), *Gunnera* (Gunneraceae), *Peperomia* (Piperaceae), and *Robinsonia* (Compositae). Little dichotomous speciation has occurred in the flora on Masafuera, with only one apparent exception: *Erigeron* (Compositae) with three endemic, closely related species. Third, apparently more ancient endemic taxa, such as *Lactoris* (the monotypic Lactoridaceae belonging to the Magnoliidae) (*26, 27*), *Juania* (monotypic genus of the apparently ancient ceroxyloid palms) (*28*), and *Thyrsopteris* (monotypic genus of the Dicksoniaceae) (*29, 30*), have dispersed to Masatierra and now survive refugially. *Thyrsopteris*, however, is known from petiolar material of the upper Cretaceous from Cerro Guido, Magellanes, Chile (*31*), and Hokkaido, Japan (*29*). The Juan Fernández archipelago can provide especially useful information on patterns of phylogeny and modes of speciation in the native flora, for several reasons. It is close to the principal continental source area; it has only three main islands, all volcanic and of known age; Masatierra is nearest the continent and Masafuera, which is younger, is in a direct line west from the principal source area for new propagules; and the flora is sufficiently small so that a comprehensive understanding of the evolution of the endemic flora can be realistically achieved.

Table 1. Potassium-argon ages of whole-rock basalts from the Juan Fernández Islands (*32*); ^{40}Ar* is radiogenic argon.

Location	Sample	K (percent by weight)	^{40}Ar* ($\times 10^{-12}$ mol/g)	^{40}Ar* (percentage of total ^{40}Ar)	Age (m.y.)
		Masafuera			
Chorro Doña Maria	9	0.400	1.784	14.9	
		0.408	1.644	15.1	
		0.403			
		Av. 0.404	1.714		2.44 ± 0.14
Quebrada Casas	8	0.872	1.535	8.5	
		0.874			
		Av. 0.873	1.535		1.01 ± 0.12
		Masatierra			
Cordon Central	3	0.737	4.886	12.8	
		0.749			
		Av. 0.743	4.886		3.79 ± 0.20
Cordon Salsipuedes	10	0.876	6.37	37.8	
		0.875	6.44	30.0	
		0.863			
		Av. 0.871	6.40		4.23 ± 0.16
		Santa Clara			
Morro Spartán	4	0.712	5.9	2.1	
		0.718	7.3	4.7	
		0.715	8.3	4.3	
		Av. 0.715	7.2		5.8 ± 2.1

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Mechanisms of Nitrogen Retention in Forest Ecosystems: A Field Experiment

Abstract. *Intensive forest management led to elevated losses of nitrogen from a recently harvested loblolly pine plantation in North Carolina. Measurements of nitrogen-15 retention in the field demonstrated that microbial uptake of nitrogen during the decomposition of residual organic material was the most important process retaining nitrogen. Management practices that remove this material cause increased losses of nitrogen to aquatic ecosystems and the atmosphere.*

Intensive management of pine plantations in the southeastern United States is accompanied by substantial removal of organic matter and nutrients during harvesting and preparation of harvested sites for replanting (*1*). These removals have raised concerns that continued intensive management could lead to reduced forest productivity. Long-term studies designed to address these concerns provide an opportunity to understand the regulation of nutrient availability and loss in forests that have been clear-cut or otherwise disturbed.

Nitrogen is the nutrient that most often limits productivity of temperate forests in the Southeast and elsewhere (*2*). After clear-cutting, losses of nitrogen by leaching and denitrification are often low, but in some sites leaching losses reach levels that reduce water quality downstream (*3*). Such losses could exacerbate any decreases in soil fertility caused by nutrient removal during forest harvest and site preparation.

The reasons for variability in nitrogen losses among sites after clear-cutting are not fully understood. Nitrogen mineralization (the release of potentially mobile inorganic nitrogen during decomposition of nitrogen-containing organic compounds) is increased in clear-cut sites (*4*), but nearly all the mineralized nitrogen is retained in most harvested sites. The major mechanisms retaining this nitrogen are uptake by regrowing vegetation (*5*), uptake by microbes during decomposition of organic material (immobilization) (*6*), and low rates of nitrification (which keep inorganic nitrogen in the relatively immobile ammonium form rather than the mobile nitrate form). Soil ammonium pools and nitrogen uptake by regrowing plants have been measured in a number of clear-cut forests (*5*, *7*), but immobilization has not been measured on an areal basis. Moreover, the degree of redundancy in these mechanisms—the extent to which a reduction in nitrogen uptake by plants, for example, would lead only to increased microbial immobilization rather than to increased nitrogen losses—has not been determined.

The experimental site we used (*8*) enabled us to test the relative importance of plant and microbial uptake in controlling nitrogen retention and loss in a clear-cut forest. The experimental design was a nested combination of high and low levels of harvest intensity (whole-tree versus stem-only harvest), site preparation [shearing, piling, and disking (SPD) versus chopping], and silvicultural treatment (herbicides versus no herbicides), replicated in three blocks (*9*). The SPD treatment removed most of the structural organic material (including residual forest floor) left on the soil surface after harvesting (*10*), thereby removing what we expected to be the major substrate for nitrogen immobilization. The herbicide treatment was designed to inhibit vegetation regrowth, thereby reducing nitrogen uptake by plants. We could thus develop an indirect estimate of the relative importance of microbial immobilization and plant uptake by comparing nitrogen pool sizes and losses (*11*) among the different treatments.

In addition, we used labeled nitrogen to measure directly the processes controlling nitrogen retention after harvesting and site preparation. Low levels of ^{15}N-labeled ammonium sulfate were applied to the surface of three laterally isolated subplots in each of 24 treatment plots (*12*). At the end of the first growing season, one subplot was harvested per treatment plot. Plants and soil were divided into components (*13*) and analyzed for total nitrogen and ^{15}N content (*14*). We expected that, if plant nitrogen uptake were more important than microbial immobilization in retaining nitrogen on site, then more ^{15}N would be recovered in plants. Moreover, we could determine

Table 1. Percentage of applied ^{15}N recovered in each treatment combination. Values are means ± standard errors for six plots per treatment

Sink	Chopping		SPD	
	No herbicide	Herbicide	No herbicide	Herbicide
Vegetation	11 ± 2	9 ± 2	13 ± 5	9 ± 3
Slash*	5 ± 2	4 ± 1	3 ± 0.3	2 ± 0.6
Forest floor	26 ± 2	25 ± 4	2 ± 0.4	3 ± 0.6
Microbial biomass nitrogen†	12 ± 1	11 ± 1	15 ± 2	13 ± 3
Soil organic nitrogen†	40 ± 4	31 ± 2	40 ± 7	42 ± 9
Total	94 ± 2	80 ± 5	73 ± 9	69 ± 11

*Organic residue on the surface with a diameter >1 cm. †In the mineral soil to a depth of 15 cm.