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THE CONTRIBUTIONS OF DONALD LEE JOHNSON TO UNDERSTANDING THE QUATERNARY GEOLOGIC AND BIOGEOGRAPHIC HISTORY OF THE CALIFORNIA CHANNEL ISLANDS

Daniel R. Muhs[1]

ABSTRACT.—Over a span of 50 years, native Californian Donald Lee Johnson made a number of memorable contributions to our understanding of the California Channel Islands. Among these are (1) recognizing that carbonate dunes, often cemented into eolianite and derived from offshore shelf sediments during lowered sea level, are markers of glacial periods on the Channel Islands; (2) identifying beach rock on the Channel Islands as the northernmost occurrence of this feature on the Pacific Coast of North America; (3) recognizing of the role of human activities in historic landscape modification; (4) identifying both the biogenic and pedogenic origins of caliche "ghost forests" and laminar calcrete forms on the Channel Islands; (5) providing the first soil maps of several of the islands, showing diverse pathways of pedogenesis; (6) pointing out the importance of fire in Quaternary landscape history on the Channel Islands, based on detailed stratigraphic studies; and (7), perhaps his greatest contribution, clarifying the origin of Pleistocene pygmy mammoths on the Channel Islands, due not to imagined ancient land bridges, but rather the superb swimming abilities of proboscideans combined with lowered sea level, favorable paleowinds, and an attractive paleovegetation on the Channel Islands. Don was a classic natural historian in the great tradition of Charles Darwin and George Gaylord Simpson, his role models. Don's work will remain important and useful for many years and is an inspiration to those researching the California Channel Islands today.

RESUMEN.—A lo largo de 50 años, Donald Lee Johnson, originario de California, contribuyó de manera significativa a brindar información sobre las Islas del Canal de California. Entre sus aportes se incluyen: (1) el descubrimiento de que las dunas de carbonato, que suelen contener eolianita, marcan períodos glaciales en las Islas del Canal, lo cual surge de los sedimentos de las plataformas de agua durante el nivel bajo del mar; (2) la identificación de la roca de playa (beach rock) en las Islas del Canal como el exponente más noteño en la Costa Pacífica de Norteamérica; (3) la identificación de la importancia de la actividad humana en la modificación histórica del paisaje; (4) la identificación del origen biogénico y pedogénico de los "bosques fantasmas" de caliche y las formas de calcreta laminar en las Islas del Canal; (5) los primeros mapas del suelo de varias islas, en los cuales se mostraban diversos senderos de pedogénesis; (6) la concientización de la importancia del fuego en la historia del paisaje cuaternario en las Islas del Canal, según estudios estratigráficos; y (7) probablemente su contribución más significativa haya sido el descubrimiento del origen de los mamuts pigmeos de la época del Pleistoceno, que no se debe a puentes continentales imaginarios, sino a la extraordinaria capacidad de nado de los proboscídeos, combinada con el nivel bajo del mar, vientos favorables y la atractiva paleovegetación de las Islas del Canal. Don fue un clásico historiador natural, que siguió los pasos de Charles Darwin y George Gaylord Simpson, quienes fueron sus ejemplos. La obra de Don permanecerá vigente durante muchos años y es una inspiración para aquellos que se dedican a investigar las Islas del Canal de California en la actualidad.

Over a span of 50 years, the late Donald Lee Johnson (Fig. 1) of the University of Illinois had a love affair with the California Channel Islands. As a physical geographer, he studied the soils, geomorphology, paleozoogeography, and Quaternary paleoclimatic history of all 8 islands (Fig. 2) during the course of his career, much of it with his wife Diana Johnson (Fig. 1). Don's work on the islands began with his doctoral dissertation on San Miguel Island (Fig. 3), awarded from the University of Kansas (Johnson 1972). Just as Charles Darwin was fascinated, challenged, and inspired by his visit to the Galápagos Islands, Don was similarly inspired by the California Channel Islands. In the several decades of his studies, Don made a number of outstanding contributions to our knowledge of these diverse islands. His work spanned the fields of geomorphology, Quaternary stratigraphy, soil science, biogeography, archaeology, and history. In a volume dedicated to the California Islands, it is fitting to include a summary of Don's contributions to our knowledge of these fascinating landscapes. This paper covers Don's work on coastal geomorphology (eolianite, beach rock), his work

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Fig. 1. Diana and Don Johnson in the field on San Miguel Island, California, sometime in the 1960s. Photographer unknown.

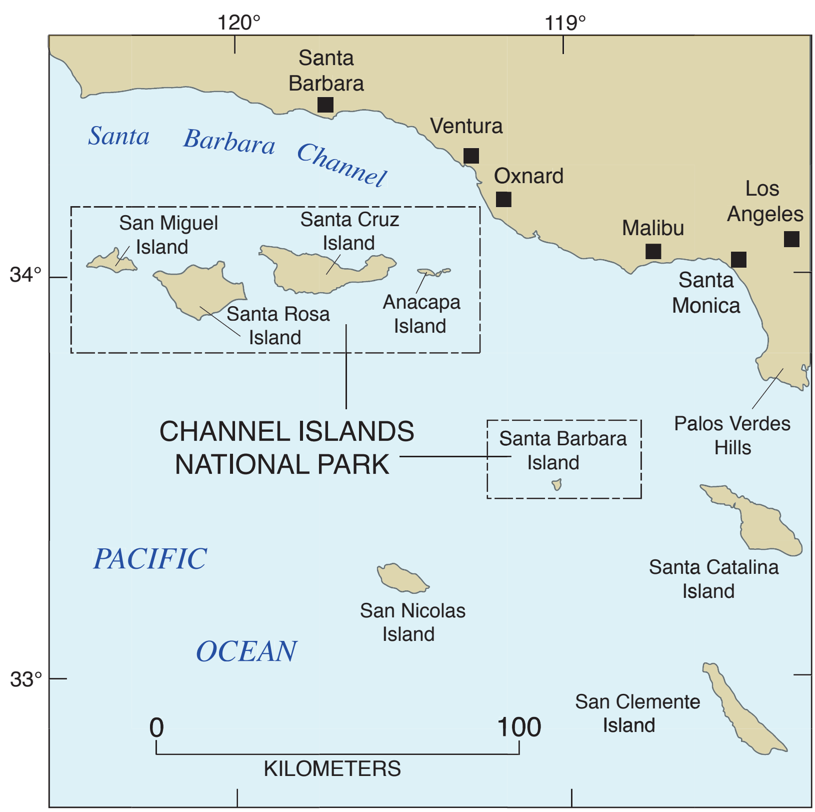

Fig. 2. Map of the California Channel Islands.

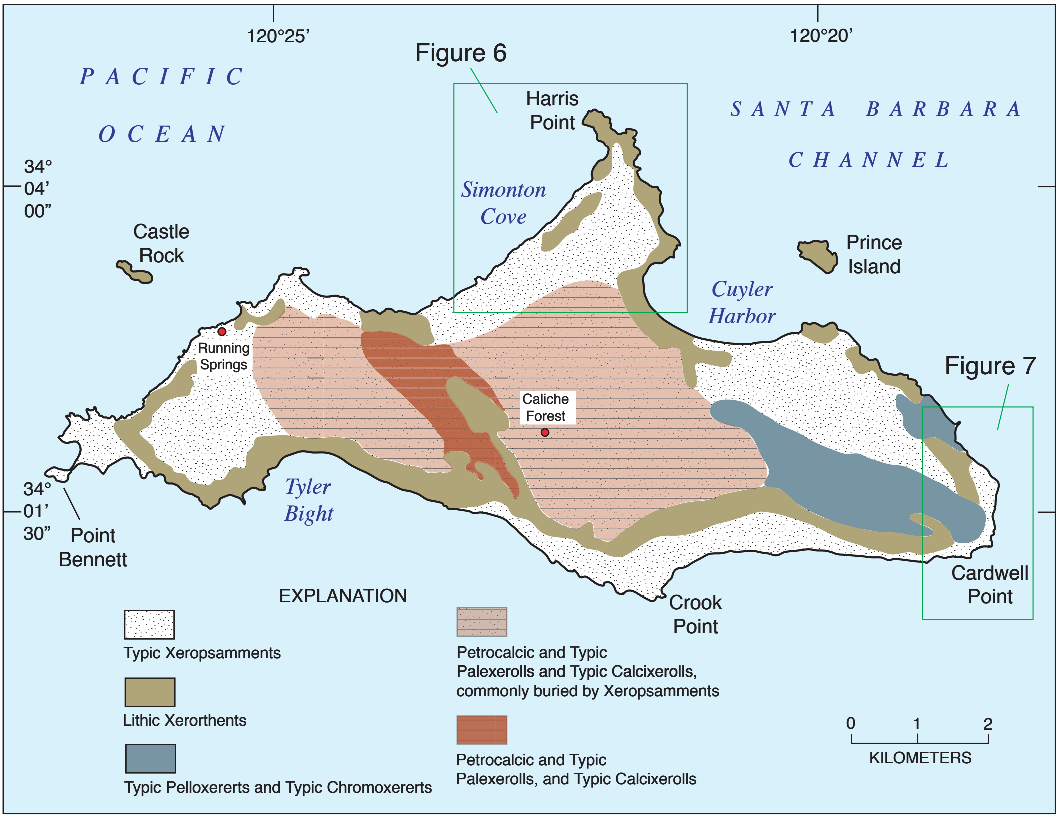

Fig. 3. Map of San Miguel Island, showing distribution of soils (redrawn from Johnson 1979) and localities mentioned in the text.

on human influences on geomorphic processes, his studies of soils (caliche, Vertisol dynamics, soil mapping), the importance of his work on soils to archaeologists, his documentation of fire history, and his work on the origin of Channel Islands mammoths and other mammals.

THE NORTHERNMOST COASTAL EOLIANITE IN NORTH AMERICA AS A PALEOENVIRONMENTAL INDICATOR

Eolianite (also aeolianite) is a term for any eolian sand body cemented into rock. The term has come to refer to carbonate-rich and cemented dunes, mostly (though not exclusively) of Quaternary age (Fairbridge and Johnson 1978). For the most part, eolianite is found along tropical and subtropical coasts, particularly islands, where carbonate production offshore is high but continental or insular shelves are not diluted by noncarbonate, sand-sized particles (Fig. 4a). On the coastlines and islands of North America, eolianite is best known from Atlantic and Caribbean coasts and is found on Bermuda, the Bahamas, Puerto Rico, and the Yucatan Peninsula. Until Don's studies, however, few geologists recognized its presence on the California Channel Islands, where it is the northernmost coastal eolianite found in North America. Don was the first to utilize these deposits on the Channel Islands for paleoenvironmental purposes.

In his earliest paper (Johnson 1967), Don showed that it is the high (~30%–70%) carbonate content of Channel Islands dunes (in contrast to all mainland California dunes) that causes them to be cemented into eolianite. He explained that the high carbonate content is due to several factors, including coastal configuration and high biologic productivity. Equally important is the fact that these are islands with small drainages. On the California mainland, large rivers drain and deliver silicate-rich (quartz and feldspars) sand from mountainous

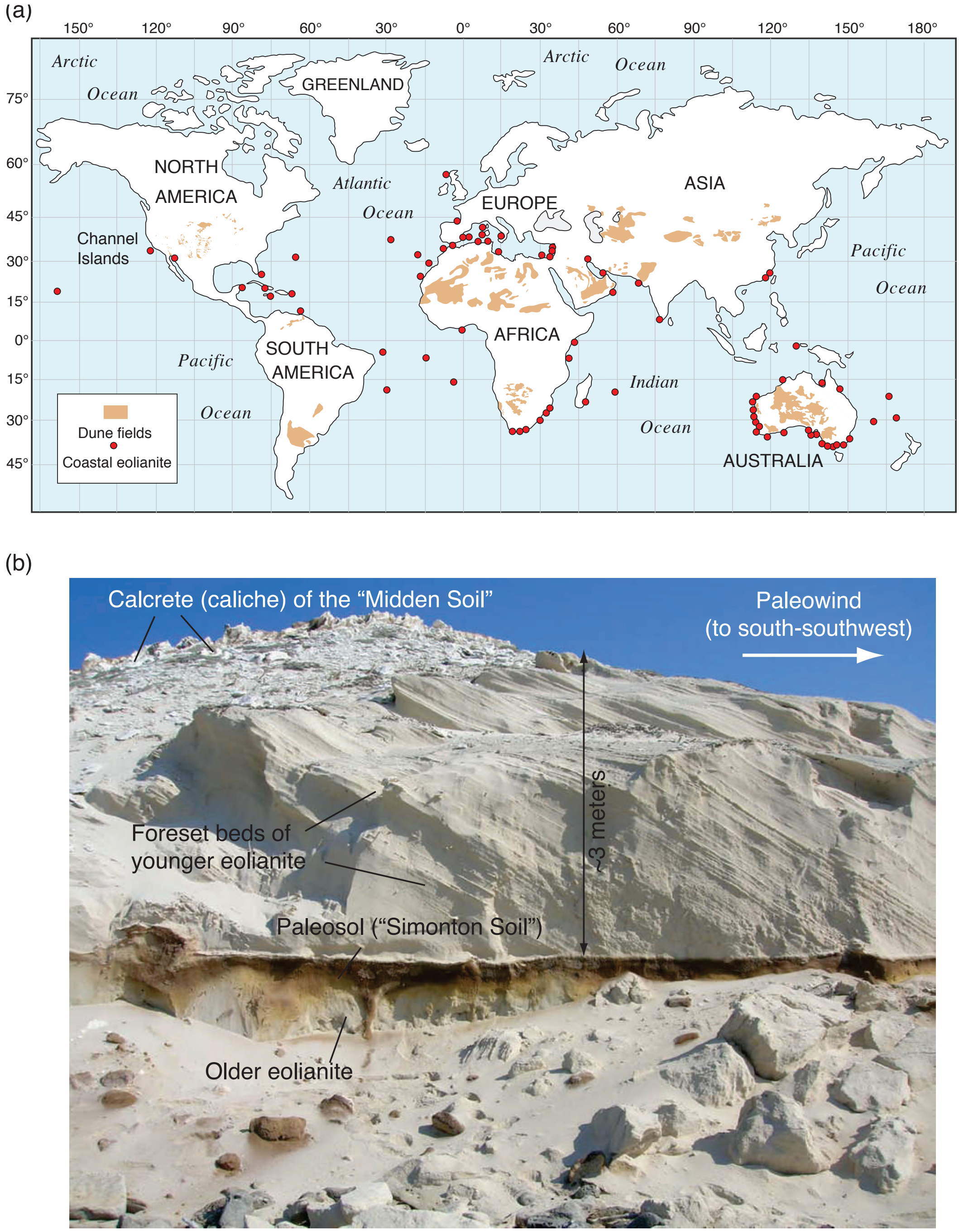

Fig. 4. (a) The worldwide distribution of eolian sand (from Sun and Muhs [2007] and sources therein) and carbonate eolianite (from Fairbridge and Johnson [1978] and Brooke [2001] and sources therein). (b) Carbonate eolianite studied by Johnson (1977a, 1980a) in exposure along Simonton Cove, San Miguel Island, and names of paleosols mentioned in the text.

terrain. Thus, even though biological carbonate production is high on the California mainland shelf, carbonate particles are diluted by quartz and feldspar from large rivers. On the Channel Islands, this dilution does not occur, and the insular shelves are carbonate-rich.

Don also hypothesized that much of the eolianite on the Channel Islands was likely deposited during the last glacial period, when sea level was low, and he cited several lines of field evidence. These observations include eolianite located where there is currently no beach source and evidence that some eolianite bodies must have once extended below present sea level. Don also reasoned that an exposed insular shelf with abundant carbonate sand, such as that which would have been exposed during the last glacial maximum (LGM), would provide an ideal source. His later work on the stratigraphy of Channel Islands eolianites, supported by radiocarbon dating, showed that this hypothesis is correct (Johnson 1977a, 1980a). His stratigraphic studies show that there was rapid emplacement of eolianite on the northwest coast of San Miguel Island between 20,130 ± 215 and 17,730 ± 300 ^{14}C yr BP (~24,000 to ~21,000 cal yr BP), coinciding closely with the LGM. However, radiocarbon ages of charcoal in eolianite that are >40,000 yr BP also show that eolianite deposition was not limited to the last glacial period. Subsequent work on other Channel Islands, both San Nicolas and San Clemente, shows that eolianites there likely also formed during periods of low sea level, both the LGM and the penultimate glacial period (Muhs 1992). Thus, Don's early work demonstrated that the Channel Islands have one of the best glacial-age indicators in the form of carbonate eolianite, derived entirely from nonglacial processes but related to glacio-eustatic sea-level lowering.

Carbonate eolianite also has paleoenvironmental significance in that it records paleowinds through high-angle cross-beds that are foreset beds of the formerly active dunes (Fairbridge and Johnson 1978). Foreset beds, sometimes poorly preserved in unconsolidated eolian sands, are remarkably well preserved in carbonate eolianite due to rapid cementation (Fig. 4b). Don noted that eolianites occur on 5 of the 8 Channel Islands but only on the northwest coasts, suggesting paleowinds from the northwest, similar to those of the present. His measurement of high-angle dip azimuths confirmed that paleowinds must have been from the northwest, consistent with the geographic distribution of these deposits (Johnson 1977a). Don concluded from these observations that the current synoptic-scale climatic controls on the southern California coast must also have been in place during the LGM.

Don also pointed out that eolianites on the Channel Islands host rich accumulations of fossil land snails (Johnson 1971). Until the early 1970s, these remarkable fossil records had received very little attention on the Channel Islands. Don's call for further studies was answered by later researchers who uncovered a fascinating series of evolutionary pathways for gastropods on the Channel Islands during the Quaternary. Notable among these are the studies by Pearce (1990, 1993) on San Nicolas Island.

THE NORTHERNMOST OCCURRENCE OF BEACH ROCK IN NORTH AMERICA

Beach rock is lithified beach sediment, with calcium carbonate acting as the cementing agent. Although beach rock is by all definitions a true clastic sedimentary rock, it can form remarkably quickly, even in a few centuries. Typically, it occurs just seaward of the modern, active beach face. Davies (1980) points out that modern beach rock is almost always found in tropical and subtropical latitudes (Fig. 5a). Because much of the Pacific coast of North America is north of subtropical latitudes, beach rock has not been reported from the continental United States.

Don, studying the contact between low-elevation marine terrace deposits and eolianite, found Pleistocene beach rock on the northern coast of San Miguel Island (Johnson 1969). This discovery, like eolianite on the Channel Islands, constitutes the northernmost occurrence of this geomorphic feature in North America (Fig. 5a). On San Miguel Island, the material being cemented is not the modern beach but rather the sediments overlying a wave-cut bench (i.e., marine terrace deposits; Fig. 5b). Given the elevation of the marine terrace, it is likely that this feature dates from some part of the last interglacial complex, or marine isotope stage (MIS) 5. The cementation, however, dates from the time of overlying eolianite emplacement. Percolating meteoric waters dissolved part of the carbonate in the eolianite sands, facilitating cementation by calcite of the underlying marine terrace clasts. Given that much of the eolianite on the Channel Islands was deposited during the LGM, it seems likely that beach rock formation on San Miguel Island must have taken place either shortly after the LGM or in the Holocene.

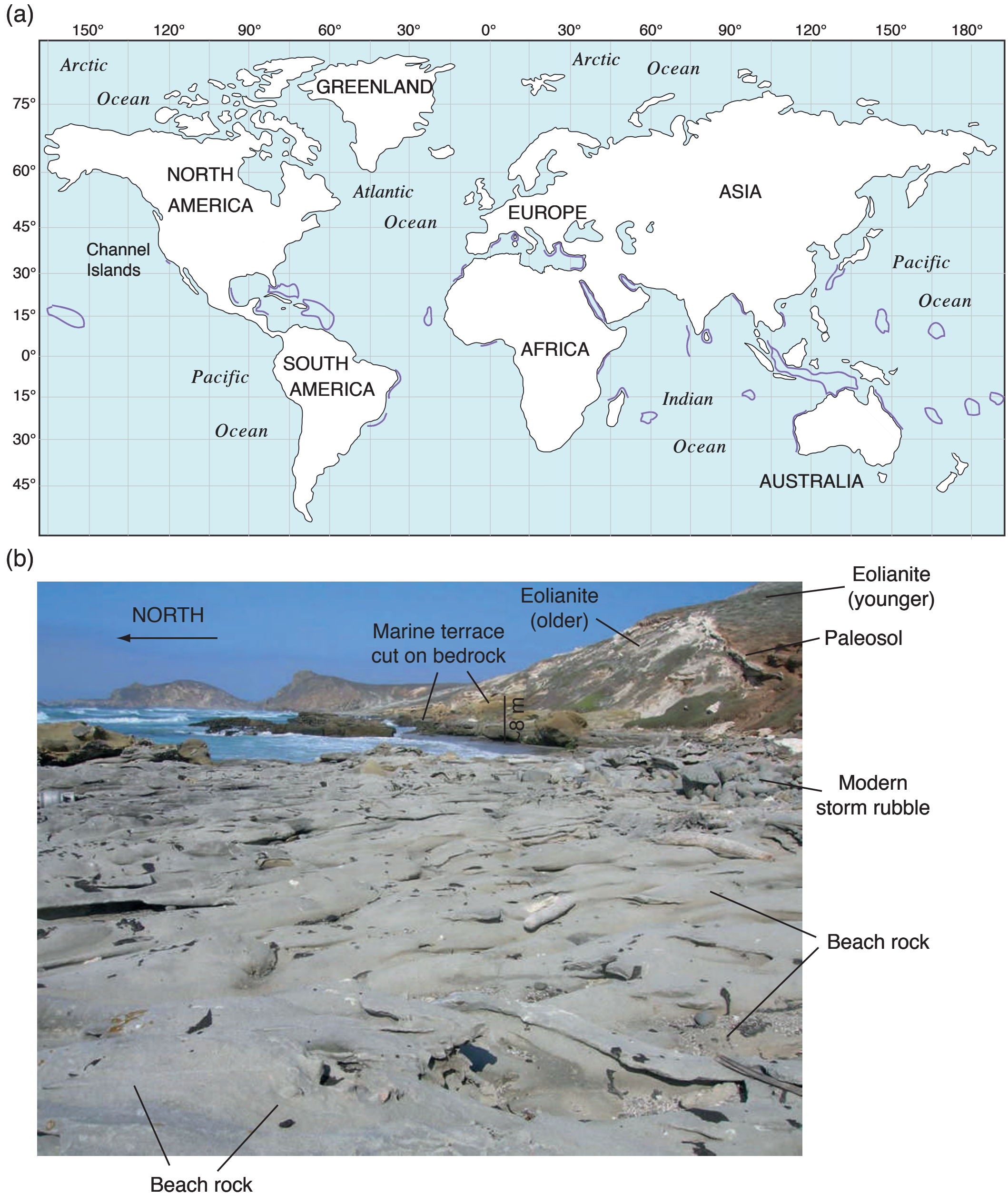

Fig. 5. (a) Map showing the worldwide distribution of beach rock (from Davies 1980). Note that distributions shown in oceans are around island chains that are too small to show at this scale. (b) Beach rock on low-elevation marine terrace, Simonton Cove, San Miguel Island, studied by Johnson (1969).

Human Influences on Landscapes in Historic Time

The role of human activities in influencing land-forming processes has been an important part of geomorphology in the 20th and 21st centuries. Don made substantial contributions in this area with his field and archival studies of the changing landscape of San Miguel Island from the mid-1800s to the present (Johnson

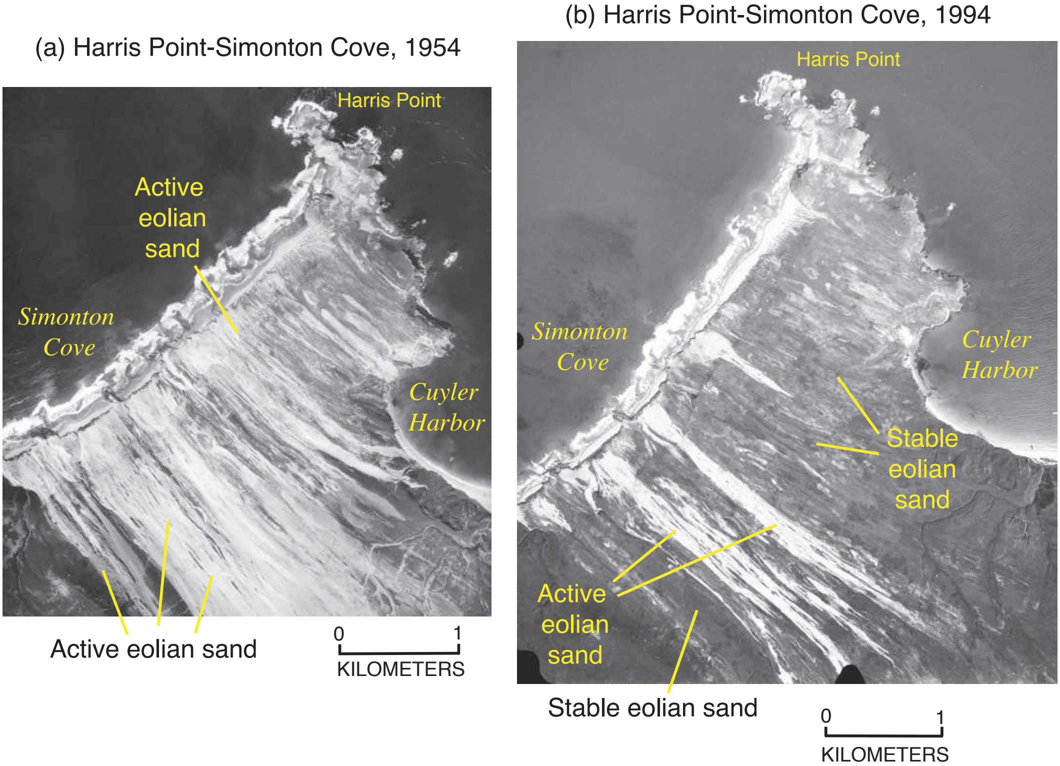

Fig. 6. Changes in degree of eolian sand activity in historic time in the Harris Point–Simonton Cove area, San Miguel Island (see Fig. 3 for location), from aerial photographs taken in 1954 (a) and 1994 (b).

1980a). His careful archival work showed that human occupation and activities on San Miguel Island had significant impacts on eolian, coastal, and fluvial geomorphology of the island.

Early U.S. Coast Survey reports show that prior to the introduction of sheep and cattle in the 1860s, San Miguel Island was well vegetated, although it lacked trees. These reports, dating from the 1850s, refer to grass and shrub vegetation and make no mention of active eolian sand. With the introduction of sheep and cattle in the 1860s and continuing through a succession of landowners until the mid-20th century, what was stable eolian sand became active over much of the island, likely due to vegetation loss from grazing. Don observed that this loss of stabilizing vegetation was exacerbated by periodic droughts in the late 19th and early 20th centuries (Johnson 1980a). By 1895, Coast Survey reports collected by Don documented active, falling dunes migrating into Cuyler Harbor (Fig. 3), and active eolian sand was widely reported by many visitors to the island. Bathymetric surveys of Cuyler Harbor document a steady infilling from 1852 to 1937 from the accretion of active eolian sand. In the early 1950s, only shortly after sheep removal, eolian sand was still highly active over much of the island (Fig. 6a). However, by 1994, after several decades of vegetation recovery had taken place, much of the formerly active eolian sand had stabilized (Fig. 6b).

In addition to changes in the activity of sand dunes on San Miguel Island, Don documented historic changes in coastal geomorphology (Johnson 1980a). Based on early maps (1871, 1893, and 1910) compiled by Don, the east end of the island at Cardwell Point (Fig. 3) apparently was a coast with a precipitous sea cliff. By 1929, based on aerial photographic evidence, Cardwell Point had developed a prominent spit due to eolian sand accretion from the island. Don showed from later aerial photographs that after the removal of sheep in 1950, the spit began to erode due to a lack of new sand supplies. A spit was still clearly present in 1954 (Fig. 7a), but by 1994 it was mostly gone and the cliffed coastline that

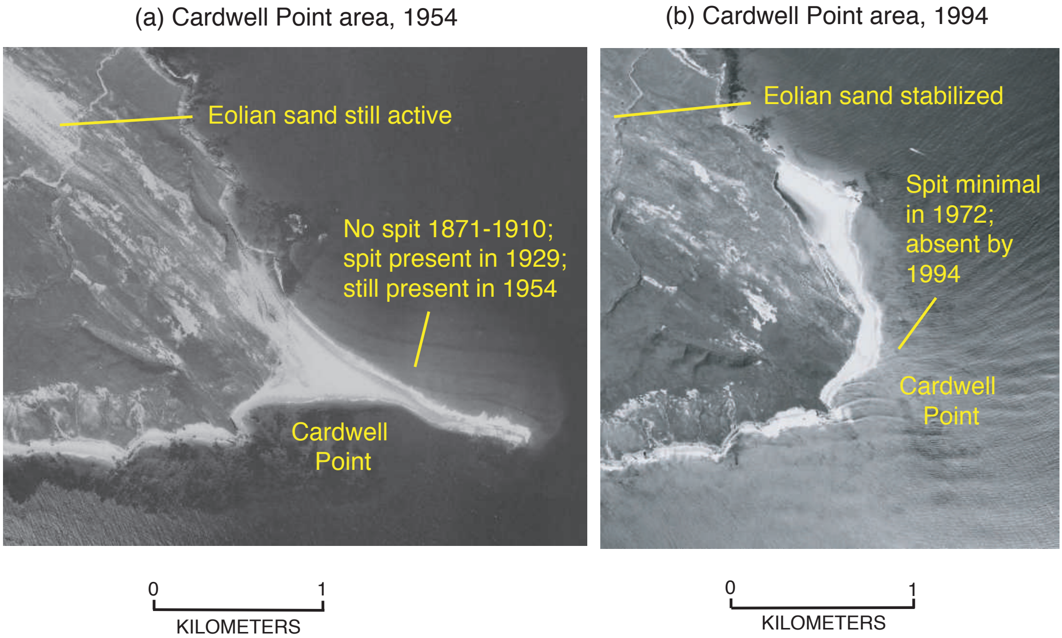

Fig. 7. Changes in coastal geomorphology in historic time in the Cardwell Point area, San Miguel Island (see Fig. 3 for location), from aerial photographs taken in 1954 (a) and 1994 (b).

was typical of the first half of the 19th century returned (Fig. 7b).

Human activities also altered fluvial processes on the Channel Islands. The 19th-century phenomenon of dramatic and widespread arroyo-cutting throughout the western United States has fascinated geomorphologists for decades (Cooke et al. 1993). Both climate change and human land use, mainly from cultivation and/or grazing, have been cited as the causes of such extensive and rapid stream entrenchment. Cooke and Reeves (1976), in one of the most detailed studies of this phenomenon, showed that in some locations, climate is the main driver of arroyo formation and in other locations, grazing is the primary cause. On San Miguel Island, Don documented deep, historic arroyo-cutting in what had previously been mapped (based on his archival work) as a cultivated field. Overgrazing by sheep, exacerbated by severe droughts, was the most likely cause of this arroyo formation (Johnson 1980a). Arroyos can be seen on other islands in California as well, and these features await detailed study.

Don's work on San Miguel Island shows how human activities over just a few decades had profound effects on the eolian, coastal, and fluvial geomorphology of the island. His careful archival work, which involved historic maps, aerial photography, and written accounts, are superb examples of how sometimes obscure data sources combined with good observations of the landscape can be highly revealing. His time-series aerial photographs showing historic landscape changes on San Miguel Island have inspired investigations into the nature of the pioneering floral species that are a part of the revegetation process (Zellman 2012).

Human activities as a cause for vegetation removal and landscape change are not limited to the historic period, as Don noted (Johnson 1980a). His speculations on anthropogenic causes of vegetation removal provided an impetus for investigators to seek evidence for this in the archaeological record (Erlandson et al. 2005, Rick et al. 2006).

PEDOGENIC AND BIOGENIC ORIGINS OF CALICHE

One of the most popular attractions for visitors to Channel Islands National Park is a stop at the Caliche Forest (also called the "Caliche Ghost Forest") on San Miguel Island (Fig. 3). Caliche (also known as calcrete, calcic horizons, or petrocalcic horizons) is common on several

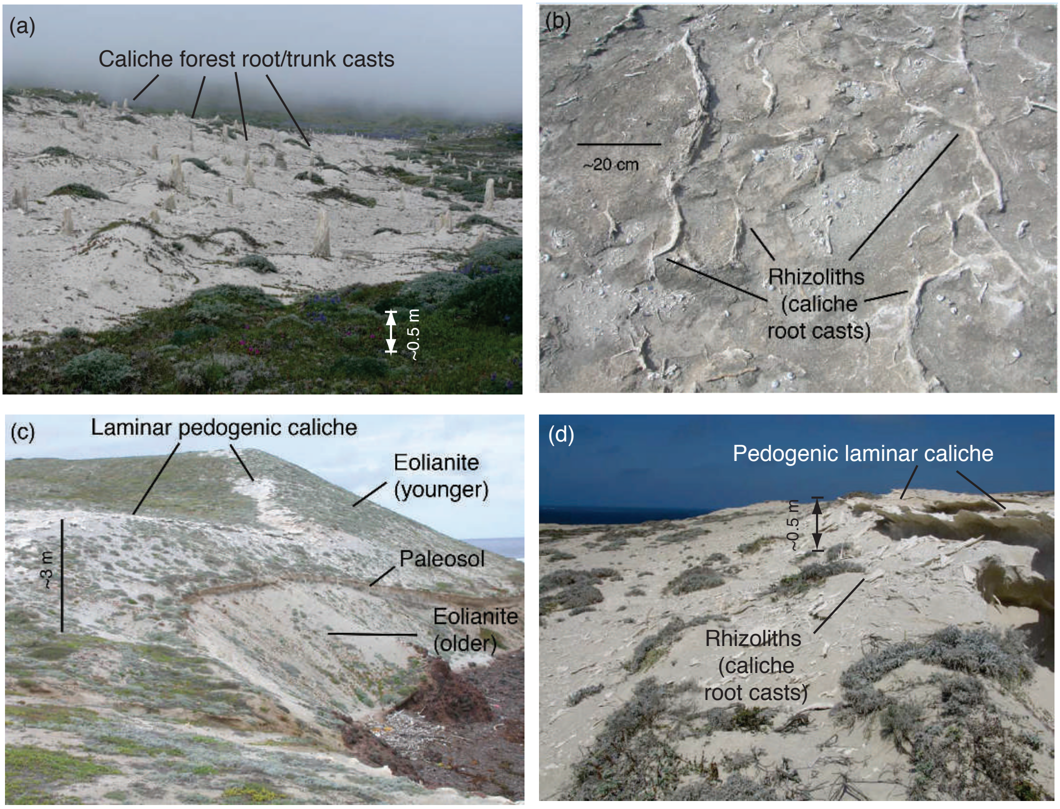

Fig. 8. The varieties of caliche studied on the Channel Islands by Don Johnson: (a) caliche "ghost forest" on San Miguel Island; (b) rhizoliths or root casts exposed at the surface by erosion, northwestern San Miguel Island; (c) laminar pedogenic calcrete following dune topography, San Clemente Island; (d) laminar pedogenic calcrete underlain by rhizoliths, western San Nicolas Island.

of the Channel Islands. In one of his earliest papers, Don showed that caliche takes an astonishing variety of forms on the Channel Islands, including dramatic tree or shrub trunk replacement products (such as those found in the Caliche Forest; Fig. 8a), extensive carbonate-replaced root systems (Fig. 8b), and horizontal laminar forms within the lower profiles of paleosols (Fig. 8c, 8d). Long before San Miguel Island became part of what is now Channel Islands National Park, in referring to the caliche root and trunk casts of the island, Don stated (Johnson 1967:152) that "it is hard to conceive of similar landscapes of equal fascination that would not have been set aside as some sort of reserve or park, were they on the mainland." This observation is an interesting foreshadowing of what was to become one of Channel Islands National Park's most popular sights.

Although there have been many studies of calcrete in soils, what is unusual about the Channel Islands is not only the diversity of forms, but the diversity of origins. Don noted that the more common pedogenic caliche is widespread on the Channel Islands (Johnson 1967). This form of carbonate accumulation occurs when climatic conditions are such that evapotranspiration exceeds precipitation and carbonates accumulate in the soil profile. On the Channel Islands, the process of pedogenic carbonate horizon formation (calcic or petrocalcic horizons in soil terminology) can be rapid, because the carbonate content of the soil parent material (eolianite) is high. Don showed that pedogenic carbonate of this sort can be easily recognized in the field because it follows the original dune topography (Fig. 8c; see also a similar photograph of the same outcrop in Johnson [1967]).

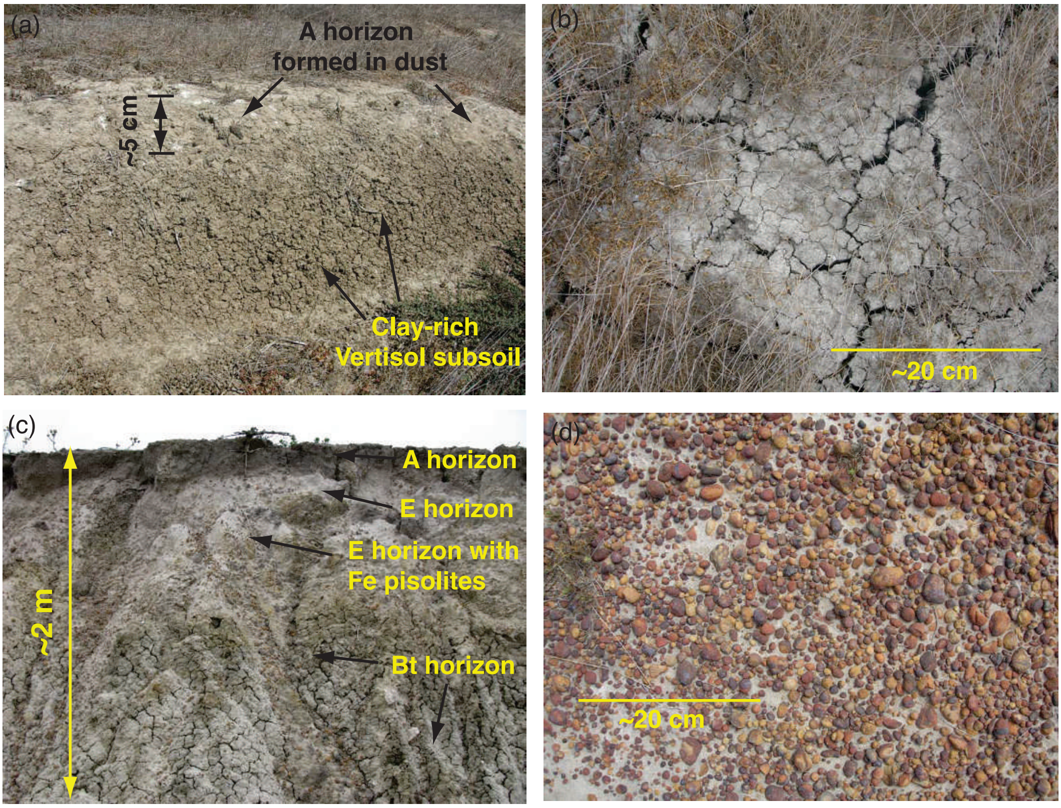

Fig. 9. Examples of soils mapped and studied by Don Johnson on the Channel Islands: (a) Vertisol with eolian silt mantle, Santa Barbara Island; (b) summer dry-season cracks in a Vertisol, Santa Cruz Island; (c) the "Green Mountain Soil" of San Miguel Island; (d) detail of Fe pisolites, as found in the E and Bt horizons of the Green Mountain Soil, exposed at the surface by erosion, Santa Rosa Island.

Despite the ubiquity of pedogenic caliche, Don also described the abundant biogenic caliche on the Channel Islands. Biogenic caliche most often takes the form of rhizoliths, or carbonate forms related to roots or trunks of plants. Such features are now recognized in many eolianites worldwide, but Don was one of the first to recognize the variety of such forms in eolianites on the Channel Islands. Rhizoliths here can be (1) a root sheath that formed around a living root and with the decomposition of the root leaves behind a tube-like form with a hollow interior; (2) root casts, which form as carbonate fills a void left by a decomposed root or trunk; or (3) hybrid forms, which consist of root casts surrounded by root sheaths. All 3 forms are common on the Channel Islands. Don inferred from the dimensions of some of these features (e.g., Fig. 8a) that a much different vegetation must have existed on the Channel Islands than is the case today, probably a greater abundance of trees. In his later thoughts on caliche, Don felt that the excellent preservation of these delicate features may be due, at least in part, to the lack of burrowing soil fauna on the Channel Islands (Diana Johnson, personal communication, 2013), a theme to which he returned in considering other soil features, discussed below.

Diversity of Soils on the Channel Islands

The Channel Islands host an astonishing variety of soil types, considering their limited spatial extent and parent materials (Fig. 9). As part of resource assessments for the newly designated Channel Islands National Park, Don generated the first detailed soil maps for San Miguel Island, Santa Barbara Island, and Anacapa Island (Johnson 1979). Besides identifying the pedogenic origin of caliche, Don made other interesting soil-related discoveries.

On both Santa Barbara Island and Anacapa Island, Don mapped Chromoxererts (Vertisols, or soils that develop cracks in the dry summer season), Argixerolls (Mollisols, or soils with dark-colored A horizons and clay-rich Bt horizons), and Haploxeralfs (Alfisols, or soils with light-colored A horizons and clay-rich Bt horizons) on flat, stable marine terraces. Steeper parts of the islands' landscapes host Xerorthents (Entisols), poorly developed soils that consist only of thin A horizons over the parent material which is usually either colluvium or weathered bedrock. Muhs et al. (2007) studied the origin of very distinctive, silt-rich A horizons in the soils of San Clemente Island, testing a hypothesis originally proposed by Don that such soils could be in part derived from eolian additions, as dust deposition (Johnson and Hester 1972). Mineralogical and geochemical evidence, as well as satellite imagery presented by Muhs et al. (2007), showed that the eolian hypothesis, first proposed by Johnson and Hester (1972), was likely correct. Don agreed to collaborate on a similar study of silt mantles on Santa Barbara and Anacapa Islands to see whether dust additions could have affected the soils there as well. The long-range-transported dust origin of the silt mantles was confirmed on these islands also (Muhs et al. 2008).

Nevertheless, a puzzling aspect in both eolian studies cited above was the distinctive silt-rich, dust-derived mantles (Fig. 9a) that were observed on the soils of the Channel Islands but not on the nearby mainland California coastal soils. If the dust was derived from sources to the east of the Channel Islands during Santa Ana winds, as the satellite imagery in Muhs et al. (2007) indicated, why weren't dust additions as silt mantles apparent on the mainland soils? Don provided the answer in our paper (see Muhs et al. 2008:124) by noting the abundance of burrowing animals living on or in mainland California soils. In contrast, the numbers and species of burrowing soil animals on the Channel Islands are very limited, particularly on the smaller islands such as Santa Barbara and Anacapa. As an example, the Botta pocket gopher (*Thomomys bottae*), one of the major bioturbators of mainland soils, especially along the coast of California, is absent on the Channel Islands and presumably has been absent during the entire time the islands have existed (Johnson 1983). The role of this animal in homogenizing the fine fraction and small pebbles throughout coastal soils, and concomitantly sorting large clasts into basal stone layers, has been well documented (Johnson 1989, 1990). Soils with such stone layers have not been recorded on the Channel Islands. Thus, as Don explained, the preservation of silt-rich eolian mantles on the Channel Islands likely reflects the dearth of burrowing taxa that act to homogenize the silty mantle with less silty materials below.

The Channel Islands also host Vertisols, soils high in expandable clays, such as smectite, that develop deep desiccation cracks (Fig. 9b) in the dry summer season. In the wet winter season, these clays absorb moisture and swell, and the cracks disappear. Vertisols are found on many of the Channel Islands, particularly where certain landscapes, such as older marine terraces, have experienced long enough periods of pedogenesis that abundant expandable clays can accumulate (Johnson 1979, Muhs 1982). On such landforms, Don noted that a peculiar situation was often present, where relatively unweathered marine terrace gravels were found on the *tops* of well-developed soils. Don's observation actually includes 2 counterintuitive characteristics because (1) well-developed soils typically retain weathered fragments of bedrock, not unweathered clasts; and (2) rounded marine terrace gravels ought to be at the *bottoms* of soil profiles, not resting on the tops. Observation of these stone pavements led Don to excavate soil pits on marine terraces on San Clemente and San Miguel Islands (Johnson and Hester 1972). His results showed that any gravels with diameters coarser than the widths of the Vertisol cracks were concentrated in the upper horizons (or on top of) the soil profiles. Don developed a model (Fig. 10) showing that the same expandable clays that cause the desiccation cracks in summer absorb enough moisture in winter that swelling pressures in the soil profile are significant. Swelling exerts pressure in all directions, but the direction of least resistance is upward because bedrock below and adjacent soil to the sides provide resistance. Thus, materials within the soil profile can migrate upward when clays that have absorbed winter moisture exert this swelling pressure. Any marine terrace clasts that make it to the surface by such movement will stay there if they are too coarse to fall back into the Vertisol cracks in summer.

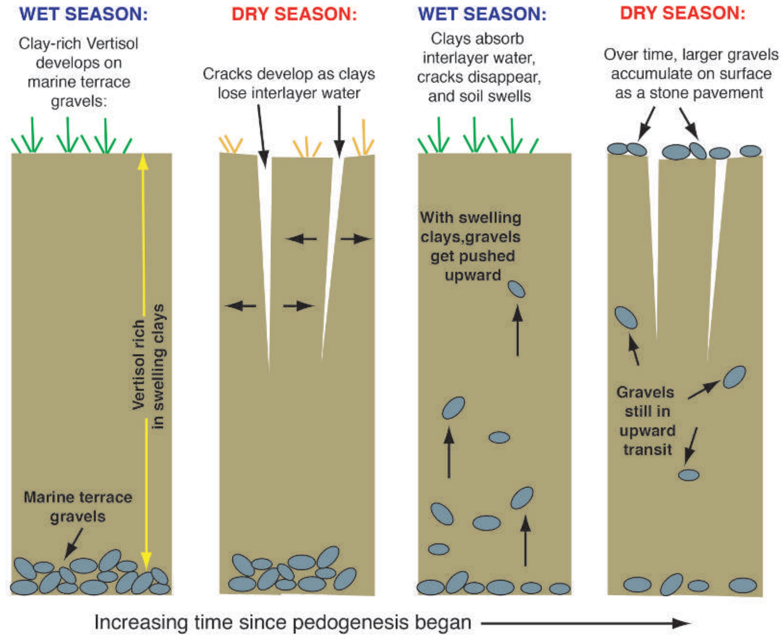

Fig. 10. Model of stone pavement development by the seasonal swelling pressure of smectite-rich Vertisols, causing upward movement of marine terrace clasts. Redrawn from Johnson and Hester (1972).

The stone pavement model described above is a significant departure from earlier concepts of stone pavements being lag deposits that result from eolian deflation of fine-grained soil particles. The classical "deflation" model had never gained much acceptance with geomorphologists, mainly because it could not explain how a stone pavement created as an "erosional lag" could have formed on top of well-developed soils. Don's mechanism reconciled the observations of stone pavements on top of soils whose degree of development required a history of minimal erosion.

Identification of the "argilliturbation" process in Vertisols on the Channel Islands is part of what led Don to explore how this and other pedoturbation processes could affect not only soil development but also the integrity of archaeological site stratigraphy (Johnson 1989, 1990, 2002, Johnson and Watson-Stegner 1990, Johnson and Balek 1991), a research avenue he pursued the rest of his career. A review paper of Don's (Wood and Johnson 1978) identified a surprising variety of ways by which soil processes could disturb archaeological site stratigraphy and artifact contexts. Rick et al. (2006), inspired by this review, summarized how these specific soil-forming processes could affect the stratigraphic integrity of archaeological sites on the Channel Islands.

Parts of San Miguel Island and Santa Rosa Island have soils that host visually striking Fe-rich spheres, often referred to as Fe pisolites or nodules (Figs. 9c, 9d). On San Miguel Island, Don pointed out that Fe pisolites are hosted by what he called the "Green Mountain Soil": a very well-developed soil that contains an A/E/Bt/C profile and can have extraordinarily thick Bt horizons (Johnson 1972, 1979). In places where erosion has removed finer-grained particles in the soil, Fe pisolites form a lag pavement on the stripped soil surface (Fig. 9d). Don was the first to point out that Fe pisolites formed in the Green Mountain Soil after stabilization and leaching of carbonate eolianite. Schulz et al. (2010) recently studied similar features in a chronosequence of marine terrace soils near Santa Cruz, California, and concluded that the nodules in those soils formed by precipitation from fungi.

Paleosols (buried soils) are another soil type Don studied in his work on the Channel Islands, and he recognized and dated some of the most important ones in 2 of his papers (Johnson 1977a, 1980a). Specifically, Don identified and named 2 late Quaternary paleosols

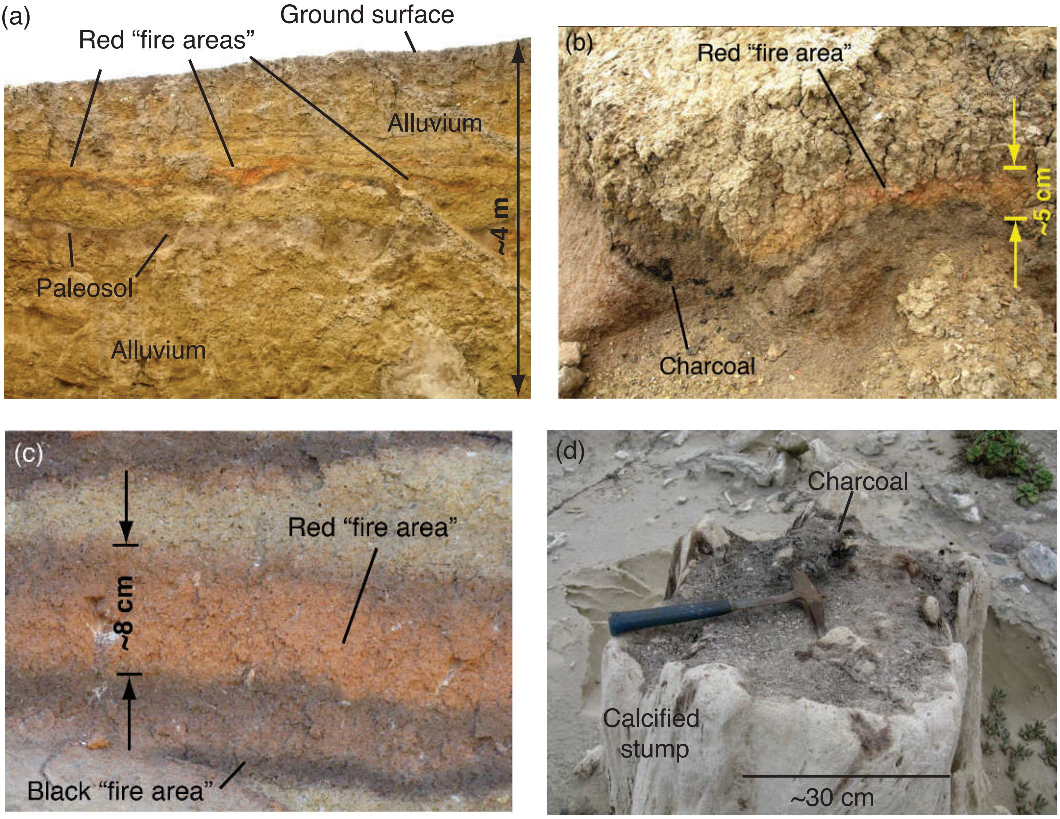

Fig. 11. Examples of fire areas on the Channel Islands: (a) and (b), Santa Rosa Island, northern coast (see Rick et al. 2012); (c) San Nicolas Island, northern coast (see Pigati et al. 2014); (d) charcoal in carbonate-replaced tree trunk, Simonton Cove, San Miguel Island (see Johnson 1977a, 1980a).

(“Simonton Soil,” older; “Midden Soil,” younger; see Fig. 4b)—both developed in eolian sand—that bracket a major period of last-glacial-age eolianite deposition. The paleosols and the intervening eolianite underlie Holocene eolian sand that hosts archaeological sites on the northern coast of San Miguel Island. Archaeologists have found that these paleosols are important markers for locating overlying archaeological sites on the island (Erlandson and Rick 2002, Erlandson et al. 2004a).

Fire as a Factor in Landscape History

Many investigators have noted the presence of what appears to be fire-altered sediment in the late Quaternary stratigraphic record of the Channel Islands. For decades these features have been referred to informally as “fire areas” of the Channel Islands. The most intensely debated of these features are reddened zones of limited areal extent (Figs. 11a, 11b) that are sometimes, though not always, an elliptical shape in cross section. Blackened areas sometimes, though not always, border the reddened zones (Fig. 11c).

The origin of these features has been debated for at least half a century. Four modes of origin have emerged from the decades of observation and discussion. The first of these is the anthropogenic origin, championed by Berger and Orr (1966), Orr and Berger (1966), Orr (1967, 1968), and Berger (1980). These investigators proposed that the fire areas are of human origin, essentially remnants of hearths that were used for heating or cooking (particularly for cooking mammoth). There are at least 2 problems with this mode of origin. One is that many of the fire zones occur in areas where there is no archaeological evidence associated with the features. A good example of this is San Nicolas Island, where a number of these features occur without artifacts and where mammoths, supposedly roasted over these fires, have never been reported. A second problem is that many of the fire areas have yielded radiocarbon ages that are far older than any accepted human presence in North America (Pigati et al. 2014).

Countering the anthropogenic mode of origin are 2 controversial but naturally occurring processes of origin. One of these is not related to fire at all, but proposes that the "fire" areas are simply zones of sediment alteration from groundwater (Cushing et al. 1986, Cushing 1993). However, the precise mechanism by which sediment can be simultaneously blackened and reddened in a short vertical distance by groundwater is not clear. Furthermore, many of the fire areas occur in sediment columns where they cannot presently be reached by groundwater and likely never could have been.

The other naturally occurring process returns to fire as a mechanism but proposes that widespread fires affected the Channel Islands, and in fact much of North America in general, after an extraterrestrial impact event, specifically, the arrival of a comet or meteor (Kennett et al. 2008). The hypothesized impact event has been vigorously debated, and a full review of the evidence is beyond the scope of this paper. However, this proposal refers to a single event that supposedly occurred around the time of the Allerød-Younger Dryas boundary, about 13,000 cal yr BP. Thus, this mechanism does not explain the origin of fire areas that are older than that age.

All 3 of the proposed mechanisms for the production of fire areas on the Channel Islands have problems, but there is also a fourth possible mode of origin. Don documented that the stratigraphic record of the Channel Islands contains abundant evidence of naturally occurring fires over much of the late Quaternary (Johnson 1977a, 1979, 1980a, Johnson et al. 1980). Such evidence includes discrete pockets of charcoal, layers of charcoal resting on paleosols, charcoal-blackened rhizoliths or calcified tree trunks (Fig. 11d), and burned and calcined bone. Ages of such materials, as determined by Don in his studies, range from ~12,000 to >40,000 cal yr BP, and these materials are found on several of the Channel Islands in both eolian and alluvial sediment. Don pointed out that fires are a natural part of a Mediterranean climate with a distinct dry season, even during the last glacial period when conditions were likely more moist on the Channel Islands. Naturally occurring fires explain the age range of fire features observed on the Channel Islands, do not require a single cosmic event, and account for the occurrence of such features both before and after the arrival of humans on the Channel Islands.

Don's early proposal that natural fires have long been a significant influence on Channel Islands landscapes has been fully corroborated in recent studies. Wendorf (1982) reached the same conclusion shortly after Don conducted his research. A carefully conducted recent study that combined detailed stratigraphy, radiocarbon dating, paleobotany, and clay mineralogy reached the same conclusions about the fire areas on Santa Rosa Island (Rick et al. 2012). Anderson et al. (2010) reported evidence of Native American burning on Santa Rosa Island which increased in the late Holocene. Nevertheless, Pigati et al. (2014) found evidence of repeated nonanthropogenic fires on San Nicolas Island, with a detailed radiocarbon chronology of charcoal ranging from ~32,500 to ~20,700 ^{14}C yr BP (~37,500 to ~24,700 cal yr BP). Thus, although humans likely have been on the northern Channel Islands since at least ~11,000–10,000 ^{14}C yr BP (or ~13,000–11,000 cal yr BP; see reviews in Erlandson et al. 2008, 2011), even the youngest ages from Pigati et al. (2014) predate the oldest archaeological sites by a significant amount of time.

ORIGIN OF CHANNEL ISLANDS PYGMY MAMMOTHS

Arguably one of Don's greatest contributions to Channel Islands Quaternary history, and to island biogeography in general, is his study of the fossil mammoths (*Mammuthus columbi* and *Mammuthus exilis*) of these islands. Like his role models Charles Darwin and George Gaylord Simpson, Don had long been interested in island zoogeography. Early in his career at the University of Illinois, Don had already made contributions to our knowledge of the origin of both foxes (prehistoric) and goats (historic) on San Clemente Island (Johnson 1975), as well as Pleistocene animal extinctions (Johnson 1977b). Don's biogeographic work on the Channel Islands (Johnson 1975, 1983, Wenner and Johnson 1980) provided the background for later work (Rick et al. 2009, Rick 2013) on how skunks, foxes, and mice reached the Channel Islands. However, it is for his work on the island mammoths that he is most frequently cited.

The origin of extinct mammoths on the Channel Islands has been debated for more than a century (Johnson 1978). Their occurrence was explainable simply by the existence of a former land bridge from the mainland to the northern 4 islands (San Miguel, Santa Rosa, Santa Cruz, and Anacapa; Fig. 2), according to a number of researchers including Chaney and Mason (1930), Stock (1943), Clements (1955), Berger and Orr (1966), Van Gelder (1965), Valentine and Lipps (1967), and Remington (1971). All of these hypothesized land bridges involved a connection between what is now Anacapa Island and the closest adjacent mainland, the Oxnard–Ventura area (Fig. 2), where the shelf is relatively shallow. The estimated timing proposed by these authors for land bridge existence varies from Early to Late Pleistocene.

There is no question that the 4 northern islands would all have been connected during the LGM due to lowered sea levels, composing a large, single island that Orr (1968) called "Santarosae." Nevertheless, Don showed that if a mainland connection to Santarosae had occurred due to glacio-eustatic lowering of sea levels, it would have required a global ice volume (during an unspecified glacial period) that would have lowered sea level by ~230–235 m (Johnson 1978, Wenner and Johnson 1980). Put in ice-volume-equivalent terms, such a sea-level lowering would have required ice sheets the size of those that developed during the LGM *plus* an additional mass or masses of ice equivalent to 2 modern East Antarctic ice sheets. There is simply no geologic evidence that such a "superglacial" period existed at any time during the Pleistocene. Furthermore, Don pointed out that the presence of multiple marine terraces on all 4 of the northern Channel Islands shows that the islands experienced tectonic uplift in the Pleistocene, implying that the distance from islands to mainland would actually have been *greater* in the geologic past (Johnson 1978). In a later study, Don partnered with structural geologist Arne Junger and used seismic profiles of the area to identify submarine terraces and other features. They showed that at no time in the Pleistocene was the water depth between the Channel Islands and mainland shallower than ~100 m (Junger and Johnson 1980). Adding to the evidence against a former land bridge was Don's observation that although mammoths were present on the Channel Islands during the Pleistocene, there were very few other mammals in the island fossil record. If a land bridge once existed, there should be records of other Pleistocene mammals on the Channel Islands.

Don proposed an alternative explanation for mammoths on the Channel Islands by documenting the remarkable swimming abilities of modern elephants, the best analog for Pleistocene mammoths (Johnson 1978). Based on careful archival research, Don showed that both African and Asian elephants are able swimmers and capable of swimming farther than the ~7-km water gap that would have existed between the Oxnard–Ventura mainland area and Anacapa Island during the LGM. During the Pleistocene, based on Don's reconstruction of LGM paleowinds (Johnson 1977a) from the eolianite record (see discussion above), mammoths might have been motivated to swim to Santarosae because they smelled the island vegetation. Island vegetation that was pristine compared to the mainland where there were competing mammal consumers could have induced at least a few mammoths to attempt the short swim to Santarosae. Don speculated that such a scenario could have occurred multiple times during the Pleistocene. Once mainland mammoths reached the islands during glacial periods, high sea levels during interglacial periods would have increased the island-to-mainland distance, possibly beyond their swimming abilities. If so, isolation on the islands would explain the dwarfing process, that is, the evolution of *Mammuthus columbi* (Columbian mammoth) to *M. exilis* (pygmy mammoth). Absence of predators would provide no advantage to large mammoths, and limited forage areas and food resources would favor small mammoths (Johnson 1978). Under this scenario, therefore, the fossil record on the Channel Islands should show both large mammoths (*Mammuthus columbi*) and the pygmy mammoths (*M. exilis*) that evolved from them. Work by Agenbroad (2012) shows that this is indeed the case.

Wenner et al. (1991) stated that by the early 1990s there was little in the way of a reliable chronology for mammoths on the Channel Islands. However, Don was one of the earliest contributors to develop a reliable chronology

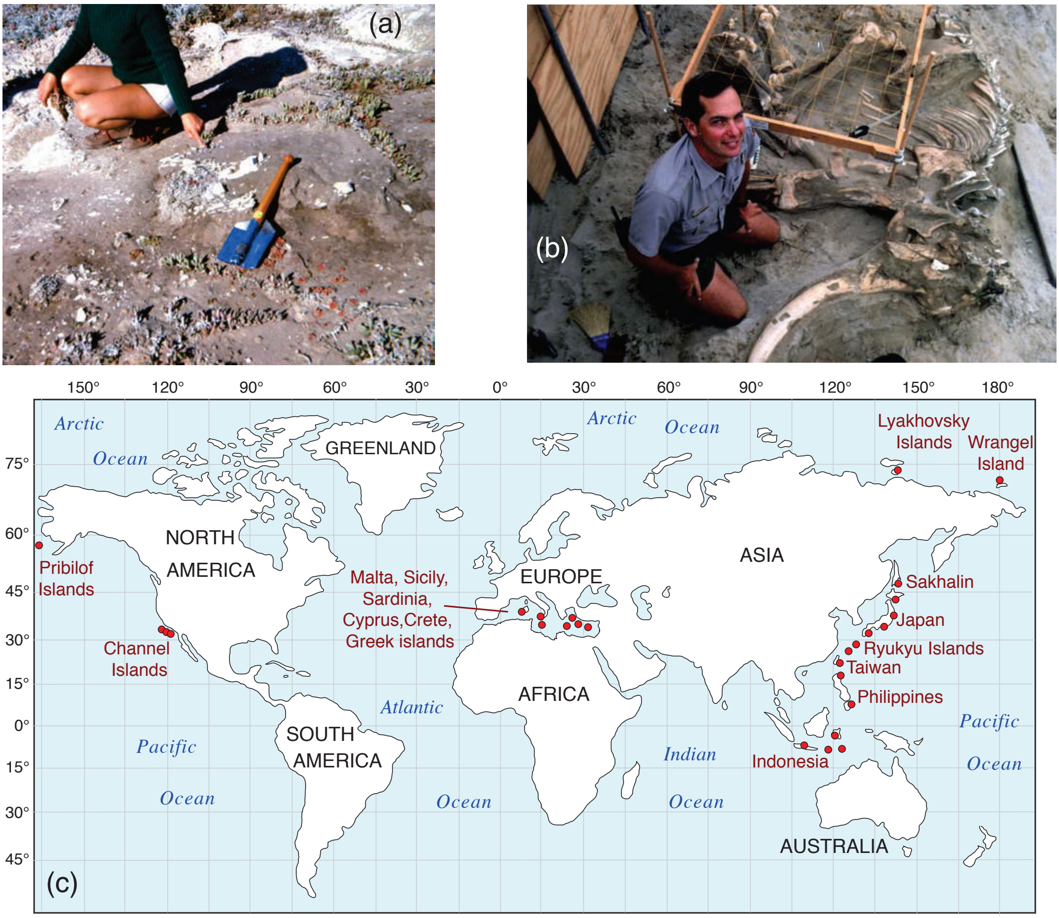

Fig. 12. (a) Diana Johnson pointing to mammoth-bone-rich sediments at Running Springs, San Miguel Island, California (see Fig. 3), where Don dated charcoal (~16,000–15,000 ^{14}C yr BP, or ~19,600–18,800 cal yr BP) in association with mammoth bone (Johnson 1981, Liu and Coleman 1981); (b) Bill Faulkner, Channel Islands National Park, next to a nearly complete pygmy mammoth (*Mammuthus exilis*) skeleton excavated on Santa Rosa Island (Agenbroad et al. 1999) and dated to 12,840 ± 410 ^{14}C yr BP, or ~15,000 cal yr BP (Agenbroad 1998); (c) map showing the worldwide distribution of fossil Cenozoic proboscideans found on islands. Distribution from Johnson (1980b), Palombo (2007), Takahashi et al. (2001), Tikhonov et al. (2003), Guthrie (2004), Poulakakis et al. (2006), Vartanyan et al. (2008), Veltre et al. (2008), Enk et al. (2009), Herridge and Lister (2012), Liscaljet (2012), and sources therein.

for mammoths on the Channel Islands. Don's work on San Miguel Island showed that one of the richest fossil mammoth sites on the Channel Islands was at a locality called Running Springs, on the northwest side of the island (Figs. 3, 12a). Running Springs has also been significant for being the location of some of the earliest archaeological records on San Miguel Island (Erlandson et al. 2004b). At this locality, Don found cypress wood charcoal from a buried colluvial soil that was in direct contact with burned and calcined pygmy mammoth bone. Radiocarbon ages (Johnson 1979, 1981, Liu and Coleman 1981) on this charcoal gave ages of 16,520 ± 150 ^{14}C yr BP, or ~19,600 cal yr BP (without NaOH leach), and 15,630 ± 460 ^{14}C yr BP, or ~18,800 cal yr BP (with NaOH leach). These ages are among the first reliable radiocarbon ages dating Channel Islands mammoths to the LGM (see review in Agenbroad 2005). In 1994, a nearly complete pygmy mammoth skeleton was discovered and excavated on Santa Rosa Island (Fig. 12b). This skeleton yielded a radiocarbon age of 12,840 ± 410 ^{14}C yr BP, or ~15,000 cal yr BP, also placing it in the last glacial period (Agenbroad 1998, Agenbroad et al. 1999).

Don's work on the origin of Channel Islands mammoths encouraged him to consider how other proboscideans reached island locations in many other parts of the world during the Cenozoic (Fig. 12c). Some island mammoths, such as those on Wrangel Island off Siberia and the Pribilof Islands off Alaska, could have easily reached their insular locations by walking because (unlike the Channel Islands) lowered LGM sea levels would have connected these islands to their adjacent mainland land masses (Guthrie 2004). However, other fossil proboscidean–bearing islands, such as certain islands of the Mediterranean, Indonesia, the Ryukyu Islands of Japan, and possibly the Philippines, are separated from mainland coasts at present and probably also were separated during lowered sea levels of glacial periods. Don pointed out, in a later paper, that the occurrence of fossil proboscideans on many of these islands could be explained by swimming rather than by imagined land bridges for which there was no geologic evidence (Johnson 1980b). This paper has been cited dozens of times by zoologists, ecologists, mammalogists, wildlife managers, paleontologists, and archaeologists studying the modern and fossil proboscidean record in the Mediterranean, the Philippines, Indonesia, and Japan. The paper is a tremendous contribution to island biogeography, all stemming from Don's careful consideration of the geologic and biologic evidence from the California Channel Islands.

SUMMARY

Donald Lee Johnson was an exceptional scientist who took a traditional natural historian's approach to studying phenomena in the geosciences and biological sciences on the California Channel Islands. He was, without a doubt, one of the most creative thinkers that many of us ever met. Don made important contributions to our understanding of Channel Islands geomorphology (dunes and eolianites, beach rock, coastal geomorphology, arroyo cutting), soils (caliche, Vertisols, stone pavements, eolian silt mantles), fire history, and biogeography (origins of island foxes, goats, and pygmy mammoths). It is rare to find an individual with such diverse interests and curiosity, as well as an uncanny ability to see how all these various natural phenomena interrelate. Best of all, Don had a great sense of humor and never took himself so seriously that he couldn't see the lighter side of things. Don was always encouraging to his friends, colleagues, and students, and his work will be a source of inspiration for Channel Islands researchers for many years to come.

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