Geology of the Seal Rock Area

By Maxine Centala
In every outthrust headland, in every curving beach, in every grain of sand there is the story of the earth—Rachel Carson

For Kathy

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Cover: Looking south near Quail Creek, sandstone of the Yaquina Formation (foreground) and basalt.
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FIGURE 1. MAP OF COASTAL OREGON AND WASHINGTON SHOWING THE LOCATION OF SEAL ROCK
FIGURE 2. MAP OF THE SEAL ROCK AREA
PREFACE

Twelve years ago I was new to the Oregon coast and eager to learn about the natural setting. Field guides were available to birds, marine mammals, tide pools, seaweeds, and forest plants. Not so geology. I looked at a field guide to rocks and minerals, but it was hard to connect those photos with the basalt and the bluff I saw at the beach. I wished for a nontechnical book about local landforms to tell me about their origin and age. To my knowledge, that volume still doesn’t exist. This work is one layperson’s attempt to fill the void and share what I’ve learned.

I discuss how the sedimentary rocks, basalt, marine terraces and sea cliffs in this area were formed and where they are visible. Also included are sections on paleontology and buried forests. Finally, a discussion of earthquakes and tsunamis looks at evidence of past activity in our locality and how these forces may affect the geomorphology of the coast in the future.

Marcel Proust once wrote, “The real voyage of discovery consists not in seeking new landscapes but in having new eyes.” Learning local geology has helped me develop a fresh eye to my surroundings and live with greater awareness of the meanings and attachments that connect us to this place, this earth: home.

This article is intended for residents and visitors interested in learning more about their surroundings. Geological information can make for dense reading, best absorbed a little at a time. I’ve kept the use of abbreviations and technical language to a minimum. Only four geologic time periods are mentioned frequently: the Oligocene and Miocene for local bedrock and basalt, and the more recent Pleistocene and Holocene for marine terraces and sand dunes. Those who wish to read in greater depth may find the list of references helpful.

Since I am not a geologist, I first read popular and scientific works, then communicated with knowledgeable people. Special thanks to geologists Tom Ore, Doris Sloan, and Curt Peterson; Tom and Doris each read the draft and gave valuable suggestions; Curt provided information and kindly clarified some complex topics. Thanks also to Wendy Niem, Vic Camp and Mario Panizza. Bill Hanshumaker gave helpful leads. Guy DiTorrice identified mollusk fossils from photographs. Kent Gibson allowed me to photograph fossils from his collection. Many thanks to Susan Gilmont, Judy Mullen and Stacy Johns for their cheerful expertise with library materials. I am grateful to friends who helped by discussing the project, making suggestions, reading an early draft or answering computer questions. And thanks to all who contributed photographs. Photos without a credit are by the author.
I. INTRODUCTION

Rocky shores, sea cliffs, and sandy beaches—these dramatic and accessible elements form the essence of the Oregon Coast. The beauty of the Seal Rock area lies in its unique blend of all three. This work is about local landforms and what they reveal of their origins. The area of focus is a seven-mile stretch of coast in Lincoln County, Oregon. It extends north from Alsea Bay to Ona Beach State Park, and about two miles inland to South Beaver Creek Road (Figure 2). The basalt of the Yachats area is also included, and volcanic rocks at Yaquina Head, Cape Foulweather and Depoe Bay, located just north of Newport, are briefly discussed.

![Aerial view of Ona Beach and the mouth of Beaver Creek, with Seal Rock in the distance.](Photo1.png)

On the edge of the continent, the Oregon Coast is geologically very young and undergoing change. On a yearly cycle, high energy storms pummel the Coast in winter. North winds in summer build dunes that are washed away the following winter. In a span of years or decades the coastline can be reconfigured by blowing sand and changing currents. Great earthquakes every few hundred years accompany subsidence of the land as well as causing destructive tsunamis. Nothing on this coast stays in place for long. Even with a scale that measures time in thousands and millions of years, Oregon is a young and actively changing part of the earth.
About Geology

Geology as a science is a work in progress. Early geologists must have been very courageous to try to understand the earth’s history by looking at nearby rocks and landforms, like detectives with vastly insufficient clues. Then came decades of exploration and mapping, with people contributing bits of information from around the globe. But it took the advent of plate tectonics to bring coherence to the assorted pieces of the puzzle. Technical innovations have since proliferated, with many geologists spending more time in the lab than in the field. However, there are still many gaps in knowledge.

Changes in geologic knowledge come often, and nothing seems to change more frequently than the ages assigned to rocks. For example, the local sedimentary Yaquina Formation used to be assigned mainly to the Miocene, but with recent advances in magnetic dating it is now assigned wholly to the Oligocene. In 2009 the International Union of Geological Sciences ruled that in accord with current geoscience, the beginning of the Pleistocene would now be considered as occurring around 2.6 million years ago instead of 1.8 million.

A final point about dates: the beginning of the Holocene is sometimes given as 10,000 years before the present, and sometimes as 11,700 years. The first number is expressed in radiocarbon years before the present, the second in calendar years. When radiocarbon dating was initiated it was not known that small fluctuations in the ratio between carbon-14 and carbon-12 occurred over time; now radiocarbon dates are routinely calibrated to arrive at calendar years.

Suggested reading for those interested in learning more about Oregon and coastal geology includes Orr and Orr (2012), Komar (1998) and Thompson (2011). Also Bishop (2003), whose book has beautiful photographs by the author though it focuses on eastern Oregon more than the coast. For those familiar with the San Francisco Bay area or interested in its complex geology, there is an excellent field guide by Sloan (2006) with a clearly written text and plenty of maps, photos and site lists for the nine-county area around San Francisco. On the geology of the lower 48 states and the geologists who study it, there is probably no better writer than John McPhee, whose four books on geology and a concluding essay about the continent’s earliest beginnings were published as a single volume in 1998 entitled Annals of the Former World. It won the Pulitzer Prize for general nonfiction in 1999.
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II. EARLY ORIGINS

Nearly all of Oregon was created when segments of the earth’s crust called terranes were added to the North American continent. The terranes were made up of volcanic island archipelagos (arcs) and pieces of ocean crust that originated elsewhere and were moved toward the western edge of North America by tectonic forces.

In plate tectonics, slabs or plates of the earth’s crust move slowly atop a partially molten or plastic layer beneath. The earth has seven major plates and many smaller ones on which the continents, oceans and islands are carried. Plates may move apart, as at spreading ocean ridges where new crust, underwater volcanoes and volcanic mountains form. Plates may also move past one another, as at California’s San Andreas Fault, or they may converge. Direct collision of two plates is an example of convergence that can result in pushing up mountains, as at the Himalayas where the Indo-Australian plate is colliding with the Eurasian plate.

Another type of plate convergence is subduction. At the Cascadia Subduction Zone off the Pacific Northwest coast, the denser Pacific plate slides beneath the lighter North American plate. The descending plate is carried deeper into the earth’s mantle until it eventually melts. The molten rock or magma eventually finds its way back to the earth’s surface in a chain of volcanoes called a volcanic arc. The Cascadia Subduction Zone and its volcanic arc, the Cascades, are shown in Figure 15.

The process of assembling Oregon began with the arrival of terranes composed of crustal blocks and island chains from elsewhere in the Pacific basin or Asia. Beginning around 245 million years ago, successive waves of terranes met the western edge of the North American continental land mass. Too thick to be subducted with the Pacific plate as it slid beneath the continent, each of these terranes instead became attached (accreted) to the continent. Following accretion they were altered or deformed as they were rotated into position.

The first terranes to arrive formed the Blue Mountains and the Klamath Mountains; they carried rocks that were originally deposited at distant locations as much as 400 million years ago. (The oldest rocks that actually formed in Oregon are at least 165 million years old, also from the Blue and Klamath Mountains. *)

By 65 million years ago, all the terranes that comprise Oregon had been accreted except one: the block that formed the Coast Range. This terrane, called Siletzia or the Siletz River Volcanics, arrived about 60-50 million years ago to form the basement rock or foundation of the Coast Range (Figure 4). Like other terranes, Siletzia also originated from underwater volcanic islands that were too thick to slide under North America, so it was added to the continent instead. Basalt outcrops of the Siletzia Terrane occur in several locations in the Coast Range; the location nearest to Seal Rock lies a few miles east of Lincoln City along Hwy 229, as shown on a map by Snavely and others (1969b).

* The oldest rock in North America, from the Canadian Shield in Quebec, is believed to be 3.8 billion years old.
After attaching to the North American plate, the Siletzia basement rock of heavy basalt subsided beneath the ocean and was covered by a shallow sea, leaving the coastline at what is now the Willamette Valley. In this shallow sea or basin atop the submerged basalt, sediments such as clay, silt, mud and organic detritus gradually accumulated. They were compressed and cemented over millions of years to form the rocks of the Tyee, Yamhill and Nestucca Formations of sedimentary rock which in Lincoln County are located east of the coastal strip.

Between 36 and 32 million years ago an interlude of volcanism occurred along the coast, forming the Yachats Basalt, Cascade Head Basalt and small deposits of related igneous rock.

Around this time the marine basin still occupied part of what is now the Willamette Valley (Figure 5). At the seaward edge of the basin, silt, sand and gravel formed deltas near river mouths, with mud and clay settling farther from shore. Rivers brought pumice and other volcanic material into the sea from ongoing eruptions in the nearby western Cascades. These sediments were likewise compressed and cemented, becoming the Alsea, Yaquina and Nye Formations.

The basalt basement rock that had been submerged in the shallow sea began to be lifted upward due to pressure from the subduction zone, which had shifted westward after the accretion of Siletzia. As uplift continued, land emerged where the sea had been. Over time hills arose and eventually became the Coast Range. The shoreline moved westward to near its present location. The sediments that once were on the bottom of the shallow offshore sea were now the sedimentary rock of the growing coastal mountains and coastal plain.

At Seal Rock, basaltic lava arrived millions of years after the sedimentary rock was formed. It was during the Miocene, around 15 million years ago, that lava from the Columbia River Basalt Group touched the Seal Rock area.

The final element to shape our topography was sand. It began to accumulate in significant amounts around 200,000 years ago to form the weakly cemented layers we see on the sea cliffs along the coast.

Much information about the nature and age of rocks in a specific locale can be found on geologic maps, which show in plan view and cross section the rock formations just below the surface. Maps also list the types of rocks present, their age, and names of formations that appear distinct. The maps published in 1976 by Snavely and others remain the basic references for this area, which is divided between the Newport and the Waldport area maps. **Surface topography is best viewed in shaded relief on the lidar map at www.oregongeology.org/dogamilidarviewer.**

**These can be downloaded free from USGS at [http://ngmdb.usgs.gov/ProdDesc/proddesc_9769.htm](http://ngmdb.usgs.gov/ProdDesc/proddesc_9769.htm) and [http://ngmdb.usgs.gov/ProdDesc/proddesc_9768.htm](http://ngmdb.usgs.gov/ProdDesc/proddesc_9768.htm). Large copies can be purchased by mail from USGS. (Product numbers 26809 and 26808; $9 each, $5 handling, 1-888-275-8747.)**
III. SEDIMENTARY ROCKS

Sedimentary rocks in this area are often beautiful and easily accessible along the beach. They contain layers that tell of sediments moved by water or wind. In some strata are inclusions that give clues about the conditions in which the sediments were deposited. Certain fossil shells may tell of a shallow marine environment. Wood and coal signify swamps. Pebbles of pumice speak of not-too-distant volcanoes.

The sedimentary rocks in this area are mainly sandstone, siltstone and clay-containing mudstone. The terms are applied according to particle size, with sandstone the coarsest and clay the finest.

<table>
<thead>
<tr>
<th>Type of Rock or Sediment</th>
<th>Grain Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>0.063 to 2mm, visible to the unaided eye</td>
</tr>
<tr>
<td>Siltstone</td>
<td>0.004 to 0.063mm, visible with hand lens</td>
</tr>
<tr>
<td>Clay, claystone</td>
<td>&lt;0.004mm</td>
</tr>
<tr>
<td>Mudstone</td>
<td>Composed of silt- and clay-sized particles</td>
</tr>
<tr>
<td>Shale</td>
<td>Composition similar to mudstone, but breaks along thin laminae or bedding layers &lt;1cm</td>
</tr>
</tbody>
</table>

Particle size can be a rough guide to water depth at which the sediments were deposited. The largest particles (gravel, sand) tend to fall out close to shore, medium particles (silt) farther, with clay particles traveling the farthest because they stay in suspension longest. After deposition, sediments are slowly compacted and gradually cemented by silica, calcium carbonate, or iron oxides.

The age of sedimentary rocks is determined using several types of information. Relative dating considers the age of strata underlying and overlying a formation. Older rock is deposited first and younger rock on top of it. Fossil plants and animals, including microorganisms and pollen, occur in an identifiable sequence through time. One formation’s fossil record can be compared to that of other strata. In iron-bearing rocks such as basalt, a record of reversals in the earth’s magnetic field can be determined from rocks and then compared with a known magnetic polarity time scale. Methods for absolute time measurement include luminescence dating and radiometric methods such as carbon-14 and potassium-argon.

In the area from Beaver Creek to Alsea Bay are portions of three sedimentary formations that constitute the bedrock in our coastal area: the Alsea, Yaquina and Nye Formations. They are visible in places along the beach and sometimes at road cuts. Elsewhere they may lie beneath sand deposits, soil and vegetation. Farther inland are slightly older sedimentary rocks, most notably the Tyee Formation, formed when a deep layer of sediments was deposited on the basement rock under what was to become the Coast Range. The Tyee Formation’s alternating beds of sandstone and siltstone can be seen in road cuts along Highway 20 east of Newport (Snively and others, 1969a,b). Figure 4 shows a generalized stratigraphic column for Lincoln County, with the oldest rocks at bottom and the youngest on top. Not all of the formations occur at all locations in the county.
FIGURE 4. STRATIGRAPHIC COLUMN FOR LINCOLN COUNTY


<table>
<thead>
<tr>
<th>Epoch</th>
<th>MYA</th>
<th>Geologic Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLEIST</td>
<td>0</td>
<td>Coastal Terraces</td>
</tr>
<tr>
<td></td>
<td>2.6</td>
<td>?</td>
</tr>
<tr>
<td>PLIO.</td>
<td></td>
<td>[Sediments from this time period are not present; most likely they eroded into the sea.]</td>
</tr>
<tr>
<td>MIOCENE</td>
<td>23.0</td>
<td>Columbia River Basalts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Astoria Formation</td>
</tr>
<tr>
<td>OLIGOCENE</td>
<td>33.9</td>
<td>Nye Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yaquina Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alsea Formation</td>
</tr>
<tr>
<td>EOCENE</td>
<td>56</td>
<td>Yachats Basalt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cascade Head Basalt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nestucca Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yamhill Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tyee Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Siletzia Terrane or Siletz River Volcanics</td>
</tr>
</tbody>
</table>
How Local Sedimentary Rocks Were Formed

It is not easy to visualize what this part of Oregon looked like in earlier time periods, with its vastly different topography and climate, sometimes above water, sometimes submerged in the sea during the millions of years that the land lifted and subsided, and the sea level rose and fell.

When this area was submerged, about 34 million years ago, the silt and fine sand destined to become the Alsea Formation was deposited in cool to cold water at depths of 300-2,000 feet (Prothero and others, 2001). These sediments have a small particle size and are fairly uniform, indicating that they stayed in suspension longer after reaching the sea. Figure 5 shows a diagram of this part of the state as it may have looked in the early Oligocene, about 32 million years ago, with a large sea occupying the Willamette Valley and land beginning to emerge along what is now the coast.

Then, around 31 million years ago the sea level began to regress due to uplift of the land. As the water near the present coast became shallower, the sediments included mollusk shells that were characteristic of a shallow marine environment. The sediments eventually lithified and became the Yaquina Formation’s lower marine member. Its location in Seal Rock is mapped in Figure 6.

As the sea level continued to regress, deltaic sediments were deposited. The deltaic nature of a portion of the Yaquina Formation is what makes it distinctive and more variable when compared to other nearby sedimentary formations, which were formed in deeper water. The Yaquina sediments were deposited in an arc-shaped area that extended from Seal Rock to Kernville. There is evidence that the location of the river mouth (or mouths) fluctuated along the arc from south to north before centering at its present location (Goodwin, 1972).

While the river delta remained above water, sediments were accumulated from the coarse sand and gravel deposited near the river mouth. Wood and plant debris from along the river settled within the sand and gravel layers, as did pebbles of pumice, basalt and other clasts carried downstream from other locations.

Plant fossils found in the Yaquina Formation east of Newport reveal that the Oligocene vegetation on the central coast was dominated by broad-leaved evergreens related to Asian flora, and was beginning to differentiate into the mixed forest of western North America, with many archaic genera disappearing. Some of the 41 genera present include familiar ones such as *Acer, Prunus, Pinus* and *Sequoia*; and others not now present such as *Debeya, Exbucklandia*, and *Laurophyllum* (McClammer, 1978).

Around 27 million years ago the sea began to rise again and the Yaquina deltas were gradually submerged. In the shallow offshore environment the silt and sand of the upper marine portion of the Yaquina Formation was deposited. Fossils known to occur in shallow seas occur again in these strata. As the waters deepened further, the fine-grained sediments accumulating on the sea bottom were different enough to be considered a separate formation, the Nye (Goodwin, 1972; McClammer, 1978; Prothero and others, 2001). Later, more sediments were deposited on this
A shallow subtropical ocean occupied the southern Willamette Valley and part of the Coast Range, as Yaquina deltas were forming off the central coast. Modified from Orr and Orr, 2012.
part of the coast and eventually hardened into rock. These later sediments will remain a mystery because they have eroded away. Any sedimentary rocks deposited in the Seal Rock area after the Nye Formation (~23 million years ago) and before the Late Pleistocene beach and dune sands arrived (~200,000 years ago) have disappeared, presumably washed into the sea. In geology, it turns out, such gaps in the geologic record, called unconformities, are not unusual.

Where to See Local Sedimentary Rocks

The **Alsea Formation** is visible in the cliff along the north shore of Alsea Bay a short distance east of the Hwy 101 bridge. Along Bayview Road it can be glimpsed in the road cut about 1.6 miles east of Hwy 101, although much of it is covered with vegetation. The Alsea Formation is also visible at the south end of Waldport. It is mainly composed of alternating layers of siltstone and very fine grained sandstone, with relatively few fossils (Snively and others, 1975).

![Photo 2. The Alsea Formation at its type locality on the north shore of Alsea Bay east of the bridge.](photo)

The **Yaquina Formation** underlies the sea cliff, beach and intertidal zone in the northern portion of the Seal Rock area. From Quail Street to Ona Beach the Yaquina forms the wave-cut platform at the base of the sea cliff. It also underlies some of the larger basalt rocks in the area, notably Elephant Rock (Photo 32).

![Photo 3. The Yaquina Formation at the base of the sea cliff](photo)

Figure 6 diagrams a portion of the Yaquina Formation along the beach in the Seal Rock area and shows the approximate locations of its three members or segments, the lower marine, the non-marine and the upper marine. As with other sedimentary rock on this part of the coast, the formation dips toward the west about 10 degrees due to the uplift and folding of the Coast Range; formations on the east side of the Coast Range dip to the east (Niem, 2013).

The Yaquina has a diverse appearance due to its formation from river delta sediments during a time when sea level fluctuated. It ranges from coarse sandstone to mudstone. The rock varies in color, appearing gray in the intertidal zone where it is not constantly exposed to air, to orangeish gray or brownish near the base of the sea cliff due to exposure and weathering (Goodwin, 1972).
Weathering of the Yaquina Formation contributes to local sandy soils that are not as prone to landslides as the soils from the nearby Alsea and Nye Formations (Schlicker and others, 1973).

About a quarter mile north of Seal Rock State Park, and also at Quail Street, the Yaquina Formation rises above the upper beach as low masses of coarse yellowish brown sandstone (Photo 10). The smooth contours of these rocks are distinctive, making them tempting to traverse and a natural resting place for beachcombers. Here the coarse sandstone shows cross bedding (for example, Photo 14). It contains various kinds of clasts, including pebbles of pumice and chert, a flint-like rock. Wood and coal fragments (Photo 12) reflect the proximity of these sediments to swamps or forests near the ancient river or rivers that transported the sediments.

In an outcrop of Yaquina Formation sandstone lies a narrow layer of clay. One day when the rocks were still damp from a hard rain, it felt softer to the touch than previously. I could scrape it away with my fingertip. Why did it remain soft after over 25 million years when the sandstone around it was, well, hard as rock? A geologist’s explanation was that hardening can vary with the particle size of the sediment. A coarse sandstone has large spaces between particles for a cement to occupy, but very small particles of clay have much less space; claystone is hardened by pressure rather than by cementation.

Between Curtis Street and Ona Beach the gray siltstone layers of the Yaquina Formation in the intertidal zone contain many spherical forms called concretions (Photos 9 and 25-30). They form when rock solidifies around a piece of shell, bone or another object. The chemical cementing around a geochemically anomalous object resists weathering better than the surrounding rock. Also there is a universal tendency for rocks to weather spherically because corners and edges decompose more easily.

Concretions can be spheres or irregular shapes. A few resemble animal shapes that to the casual observer might be mistaken for a fossilized creature. Some of the concretions near the sea cliff at
Ona Beach have centers of iron-rich limonite, a softer mineral that erodes faster than the surrounding material (Photo 28).

The Yaquina Formation contains abundant macrofossils (Photos 20, 21), mainly bivalve mollusks or pelecypods (clams), especially in the upper marine portion.* Here the shells occur in layers, with many disconnected and fragmented, indicating that they were deposited after the organisms died. The shells may have been concentrated into layers by currents or wave action (Goodwin, 1972). Bishop (2003) hypothesized that the shell layers might be explained by an event such as an earthquake or tsunami that roiled the bottom sediments and shells into suspension, after which they would settle out in layers according to weight or size.

Just south of Ona Beach the siltstone of the Yaquina Formation begins a transition to the mudstone of the Nye Formation. The division between the formations is diffuse, not readily apparent to an observer on the beach. The current USGS map places the Yaquina-Nye juncture near the south bank of Beaver Creek. An earlier geologic map (Vokes and others, 1949) placed the boundary about a half mile south of there.

The Nye Formation, about 23-27 million years old, overlies the Yaquina Formation and interfingers with it where the formations meet in the Ona Beach Area. The Nye is visible as the shore platform at the base of the sea cliff north of Beaver Creek. It is dark colored and clay-like in appearance, slightly slippery and rather easily crumbled.

Photo 4. Mudstone of the Nye Formation along the beach north of Beaver Creek.

* The Astoria formation north of Newport is even more prolific with macrofossils.
SOME CHARACTERISTICS OF LOCAL SEDIMENTARY ROCKS

**Bed**—the smallest unit of sedimentary rock; a single stratum or layer of deposited sediment. Beds have well-defined planes separating them from layers deposited above and below (Photo 15).

**Cross bedding**—sediments deposited at an incline as a result of wind or water currents, sometimes revealing the direction of the current. Boundaries between sets of cross beds often represent an erosional surface (Photo 14).

**Trough bedding**—A type of cross bedding with the lower surface curved or scoop-shaped (Photo 16).

**Clasts**—Particles of various sizes that make up a rock. Angular particles originated near the source, while smooth ones were water- or wind-worn over time, either in place or during transport.

**Conglomerates and breccias**—rocks containing clasts over 2 mm; called conglomerates if pieces are rounded, breccia if angular.

**Fossils**—animals or plants or their traces preserved in rock.

**Wood and coal**—inclusions of both are present, from <1 to 24 inches long; coal is compressed and chemically changed wood and other plant material from swamps (Photo 12). A 1mm thickness of coal roughly equals a 5-10cm layer of the original material.

**Bioturbation**—burrowing by bottom-dwelling invertebrates preserved in sedimentary rock, usually across bedding layers; a few can be identified by burrow size and shape (Photos 23-24).

**Concretions**—rounded rock forms a few inches to several feet in diameter; harder than surrounding rock; common in the intertidal strata just south of Ona Beach State Park (Photos 9, 25-30).

**Pelecypods**—a group of bivalves or shellfish that includes oysters, clams, mussels, and cockles.

Piddock clams (Family Pholadidae) A discussion of local sedimentary rock would be incomplete without mentioning pholads such as the piddock clam, which burrow into mudstone and other soft rock using the ridges at one end of its shell. Its burrow is shaped by the rotating of the clam as it grinds the rock. As it digs deeper and enlarges its burrow it grows larger; as a result it cannot back out of the hole. Its lives up to 8 or more years, and can survive for months in rock that has been buried by sand. The piddock is related to the wood-boring marine mollusk *Teredo* or ship worm (Cowles, 2006; Coan and others, 2000). In the Seal Rock area the most common species is the flat-tipped piddock clam, *Penitella penita*, with a whitish shell 1½-3” long. Piddock clams were sometimes called “rock oysters” and in historic and prehistoric times have been used for food.
Photo 5. Flat-tipped piddock clam. Courtesy of Oregon Department of Fish and Wildlife


PHOTO SECTION: THE MANY FACES OF THE YAQUINA FORMATION

Photo 8. Yaquina Formation emerging at low tide near Curtis Street.

Photo 9. Concretions in the upper marine segment south of Ona Beach.

Photo 10. Non marine portion of the Yaquina south of Curtis Street.

Photo 11. The Yaquina Formation as bedrock in the intertidal zone.

Photo 12. Coal fragments in coarse deltaic Yaquina sandstone.

Photo 13. Yaquina Formation mudstone near Curtis St.
YAQUINA FORMATION: PRIMARY SEDIMENTARY STRUCTURES

Photo 14. Cross bedding in sandstone of the Yaquina Formation.

Photo 15. Thin horizontal beds of silt layered within sandstone.

Photo 16. Large trough bedding near Quail Street beach.

Photo 17. A layer of deformed ripples at Quail Street beach.

Photo 18. Ripples in sandstone north of Quail Street beach.
YAQUINA FORMATION: FOSSILS AND BIOTURBATION

Photo 19. Interior cast from a fossil bivalve *Chione*.

Photo 20. *Anadara* clam preserved in the Yaquina Formation.

Photo 21. A fossil layer near the sea cliff south of Ona Beach.

Photo 22. Portion of a tree preserved in sandstone.

Photo 23. Bioturbation: a burrow preserved in siltstone.

Photo 24. Marks from burrowing by unknown species.
YAQUINA FORMATION: CONCRETIONS

Photo 25. Rounded concretions north of Curtis Street

Photo 26. More unusual shapes

Photo 27. Rows of concretions washed by the surf near Ona Beach.


Photo 29. Concretions adorned with seaweed in the intertidal zone.

Photo 30. Intertidal concretions as seen in spring, with sand returning.
Tom Ore

Tom is a geologist who responded to the author’s request for help in identifying and understanding local geologic features. His extensive knowledge and his ability to clearly explain geologic concepts to a neophyte were invaluable to this project.

He moved to the Oregon coast in 1997 after teaching for 34 years at Idaho State University. He began his professional career at one of the most exciting and rapidly changing times in geoscience. The discovery of seafloor spreading and associated magnetic reversals led to the theory of plate tectonics, which led to understanding the connection between the seismicity, mountain-building, volcanic activity and ocean trench formation that occurs on plate boundaries.

After receiving his PhD from the University of Wyoming, Tom specialized in sedimentology with emphasis on the Tertiary and Quaternary. During his career at Idaho State he initiated field camps for geology students, taught many different geology courses, and served for a time as department chair. Later in his career, his research emphasis shifted to geomorphology. He was also a licensed pilot, which he says was handy for aerial viewing of land forms.

Tom and his wife Janis live in Waldport.
IV. BASALT AT SEAL ROCK

Basalt is the most visible and durable of local rock formations, comprising Seal Rock’s iconic Elephant Rock and associated rocks that extend over a mile and a half along the coast and nearly half a mile from shore. Seal Rock’s basalt was deposited about 15 million years ago during the Miocene.

One of the most common rocks on earth, basalt is usually gray to black in color. It weathers to brown or rust-red due to oxidation of its iron-rich minerals. It almost always has a very fine-grained mineral texture due to the molten rock cooling too quickly for visible mineral crystals to grow. The kind of basalt here, called tholeiitic basalt, is relatively rich in silica and poor in sodium. It is also high in iron and magnesium. A chemical analysis of coastal basalts that includes one sample from Seal Rock can be found in Snavely and others, 1973.

The basalt here is younger than the sandstone bedrock by 10 million years or more. At Seal Rock State Park and the beach at Quail Street it is possible to see portions of a basalt sill perched directly atop the Yaquina Formation sandstone.

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**Definitions**

**Basalt** (buh salt’)—a fine-grained volcanic rock that is low in silica and high in iron and magnesium, which give it its dark color.

**Breccia**—a rock composed of angular fragments of basalt (Photos 54-59, 75)

**Dike**—a flow that cuts across layers (Photos 63, 73).

**Magma**—molten rock while still in the earth, before it erupts.

**Sea stack**—a landform consisting of a steep or pillar-like column of rock near a coast that was detached from shore by erosion (Photo 31).

**Sill**—a lava flow that oozed between layers of surrounding rock.

**Subaerial**—literally “under the atmosphere;” a surface flow, not underground or under water.

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When this area was mapped by USGS in the 1970s, basalt formations on this part of the coast were described as intrusive sills and dikes of Cape Foulweather basalt (Snavely and others 1976a,b,c). Because of the curvature of some of the basalt emplacements, especially at Otter Rock, it was thought to possibly form part of a ring dike. Because ring dikes were normally associated with volcanic lava vents, it was believed that there must have been volcanoes in this area.
The geologists had always recognized, though, that Oregon coastal basalts were very similar to basalt from the great lava floods in eastern Oregon, eastern Washington and Idaho. Still, based on the standard interpretation of the dikes and sills at that time, they were convinced that vents must be near the coast.

In 1979, Marvin Beeson of Portland State University proposed an alternative hypothesis: that the lava originated over 300 miles away as part of the Columbia River Basalt Group, and had flowed all the way to the coast (Beeson, 1979). Over the years, Beeson and a colleague collected evidence through magnetic and gravitation studies (The force of gravity varies a miniscule but measurable amount as rock density changes.) (Pfaff and Beeson, 1989). Geologists have since accepted that lava from the Columbia River Basalt Group did indeed reach the coast. Seal Rock is the southernmost location of these basalts, which extend as far north as Grays Harbor, Washington.

How Lava Reached the Seal Rock area

Seal Rock’s basalt was part of the Gingko flow of the Frenchman Springs Basalt, which is classified as belonging to the Wanapum Member of the Columbia River Basalt Group. It was emplaced 15.6 to 15.3 million years ago. Beeson and others suggested that the lava traveled to this part of the coast down a Columbia River paleochannel into the Willamette Valley, then turned westward from Salem toward the Newport area. It would have followed a stream valley to cross what were then the low hills of the Coast Range as shown in Figure 7. Most traces of Columbia River basalt between Newport and Salem are gone, having been deformed and eroded by the uplifting of the Coast Range. At the time of the Gingko flow, the coastline at Seal Rock was very near its present location.
FIGURE 7. MAP OF THE COLUMBIA RIVER FLOOD BASALTS

Upper: Extent of Columbia River Flood Basalts including Steens Basalt. Lava sources include CJD= Chief Joseph dikes, MD= Monument dikes, SD= Steens dikes.
Lower: Gingko Flow of the Columbia River Basalts showing possible route to the coast from Salem.

Redrawn from Camp and Ross, 2004 (upper); Ho and Cashman, 1997 (lower).
THE COLUMBIA RIVER BASALT GROUP

The Columbia River Basalt Group was one of the largest and farthest-traveled lava floods to occur on the earth. Over a period from about 16.6 million to 6 million years ago it emerged intermittently, with most of the lava emitted in the first two million years. It flowed from groups of vents in eastern Washington, eastern Oregon, and Idaho. The total amount emitted was over 56,000 cubic miles, including the Steens Mountain basalts that are now considered to be part of the Columbia River Basalt Group (Camp and Ross, 2004; Tolan and others, 2009).

After filling what is now the Columbia Plateau, the lava kept flowing westward. The basalts lining the Columbia Gorge are part of these flows. About 30 separate flows from the Grand Ronde, Wanapum and Saddle Mountains Members of the Columbia River Basalts reached the western Columbia Gorge or the Pacific coast of Oregon and Washington (Wells and others, 2009).

The ages of some of the Columbia River basalts were revised in 2002 by Hooper using argon-argon dating, a technique designed to replace potassium-argon dating. That study dated the main part of the Columbia River/Steens Mountain flows between 16.6 and 15 million years ago (Hooper and others, 2002).

The lava probably traveled much of the distance from eastern Oregon in a rapid, subaerial sheet flow. Just before reaching its western limit, the molten substance moved into sedimentary rock layers and spread downward, laterally or upward as it found voids and fractures in the rock. When it encountered wet unconsolidated sediments, it burrowed into them with little disruption of the layers.

A fast laminar flow with an insulating crust could have arrived here in six days from vents in eastern Oregon. A University of Oregon study of temperature loss during the Gingko flow concluded that the lava was 1085 +/- 5 degrees C. and lost a maximum of 20 degrees C., and probably less, during the 400-500 km between the vents and Yaquina Head. This small temperature loss was the basis for calculating the 6-day transit time. The authors concluded that it may have taken longer if it involved flow inflation (Ho and Cashman, 1997). Flow inflation, involving sequential pulses of lava that enlarged the original skin formed on the flow lobes, would also explain the sheet-like structure of flood basalts (Hon and others, 1994).

The form that the emplaced basalt finally assumed was a result of cooling rate and position within the flow. Cooling happened first in portions that contacted moisture, then at the top and bottom of the flow where the lava contacted air or rock. Where angular basalt mixed with loose sediments or broken sandstone, the result was breccia (Photos 54-59). Near the southern end of the basalt in Seal Rock, wet sediments and hot lava collided, engulfing pieces of basalt and sandstone in a churning, steamy mixture that resulted in peperite (Photo 57), a type of breccia...
named for its resemblance to a sprinkle of black pepper (Snavely and others, 1973). Slower cooling in the interior of the lava sill resulted in columns of basalt such as those on Elephant Rock, in smaller columns that assume similar forms (Photo 47), or in blocky masses of basalt.

Photo 32. Basalt of Elephant Rock overhangs the eroded Yaquina Formation sandstone beneath.

How much basalt was originally deposited at Seal Rock? The sandstone that once overlay the lava sill has long since eroded away, leaving no way to determine how high the basalt once stood or what percent of the original rock remains after 15 million years on an active coastline (Niem, 2013).

The headlands and sea stacks that we see today are examples of inverted topography. As the lava oozed through sandstone and moist sediments, it would have filled low spots and deformed the unconsolidated layers. Later, more sediments were deposited and the land was tectonically uplifted. The sedimentary material eroded faster than the basalt. Therefore, the areas that were once low spots eroded least. They are the basalt headlands and sea stacks we see today (Orr and Orr, 2012).
Where to See Basalt in Seal Rock

There are three main access points to the basalt at Seal Rock. Quail Street is the southernmost. If the tide is very low and you don’t mind walking over cobbles and climbing low outcrops it is sometimes possible to walk to Seal Rock State Park, the main access.*

At the state park, a paved trail leads down to the beach. At Curtis Street, about a mile north of Seal Rock, one can park and walk the beach south for a good view of Castle Rock and other basalt sea stacks.

Photo 33. Remnants of the basalt sill emplaced at Seal Rock, with Elephant Rock in the distance.

What to see: sills and dikes; columns and other jointing patterns; breccia and peperite.

1. Sills and dikes. Elephant Rock is one of several basalt sills perched atop Oligocene sandstone of the Yaquina Formation. Similar structures are near Quail Street. In both locations the sandstone is eroding faster than the basalt. Figure 8 shows some of the basalt dikes and sills that were identified at Seal Rock State Park.

2. Jointing characteristics. When lava cools it begins to contract, resulting in development of cracks or joints. Simple flows often have a lower section of large columnar joints called a colonnade. The middle section, called entablature, may have a convoluted pattern of joints. An upper colonnade of shorter columns may also be present. In a case where lava contacts moist sediments, according to volcanologist Victor Camp,*

* Please do not climb on rocks during April through July, lest you disrupt the nesting of the black oystercatcher. They are a species of concern in Oregon. Rocky shores are the only environment in which they nest and raise their young.
FIGURE 8. SEAL ROCK BASALT DIKES AND SILLS

“The columns will always align perpendicular to the surface upon which they cool. In a chaotic mixture of basalt lava and wet sediment, you will get basalt invading into the sediment at different orientations, so that the columns will form at angles to the normal orientations. Likewise, if sediment shoots up into the flow, the columns will form perpendicular to the cooler, injected sedimentary surfaces” (Camp, 2013).

Photo 34. Horizontal columns just north of Castle Rock.

3. Breccia and peperite. These are rocks formed at an outer edge of a flow, where lava contacts and mixes with rock or sediment. There are many variations at the beach near Quail Street, where sandstone may contain pieces of basalt, and some basalt has incorporated chunks of sandstone. The result looks like a confused mingling of lava, sandstone, and wet sand. In one location it appears that fragments of basalt formed an exterior crust of a lighter color as they were engulfed in the mixture (Photos 54-59).

Volcanologist Victor Camp:

“The overall deposit of where basalt mixes with moist sediment is called a peperite. The pictures [taken at the beach near Quail Street] make it clear that the sediment was wet and unconsolidated. In this case the Gingko flow "invaded" loose, wet, unconsolidated sediment. We use the term "invaded" as opposed to "intruded" because this is a surface phenomena where the flow burrowed into the loose sediment due to its higher density. The result is a chaotic mixture of the two rock types” (Camp, 2013).
A remaining question: why is some of the basalt off Seal Rock aligned in curves, or parts of rings? Because we now know that the lava arrived from eastern Oregon and not from volcanic vents on the coast, these are not actually ring dikes along our coast, although use of that older term lingers. So what caused the curves and semicircular structures? One answer suggested was that the lava may have moved through curvilinear fractures in the local rock as it flowed into this area. What might have caused the curvilinear fractures has not been studied (Niem, 2013).
PHOTO SECTION. BASALT AT SEAL ROCK: SURFACES

Photo 36

Photo 37

Photo 38

Photo 39

Photo 40

Photo 41
BASALT AT SEAL ROCK: FORMS

Photo 42

Photo 43

Photo 44

Photo 45

Photo 46

Photo 47
WHEN BASALT MEETS SANDSTONE

Photo 48

Photo 49

Photo 50

Photo 51

Photo 52

Photo 53
WHEN BASALT MEETS WET SEDIMENT

Photo 54

Photo 55

Photo 56

Photo 57

Photo 58

Photo 59
Doris Sloan’s life changed at age 40 when, after raising four children and working a desk job, she spent a week enrolled in a geology class in the Sierra Nevada. She discovered a love for geology and teaching that propelled her to return to school, where she received a M.S. in geology in 1975 and a Ph.D. in paleontology in 1981, both from the University of California at Berkeley. She taught environmental science at Berkeley for many years, and led geology field trips in the San Francisco Bay area and elsewhere.

In addition to publishing scientific articles, in 2006 Doris wrote *Geology of the San Francisco Bay Region*, a superb field guide that made the area’s geology accessible and understandable to lay people as well as geologists.

Doris is also an active environmentalist, working with several organizations around San Francisco. In the 1960s she helped stop a nuclear power plant from being built near the San Andreas Fault. She worked with Save the Bay to prevent a massive development on the wetlands of San Pablo Bay. She also wrote many popular articles about the outdoors for *Bay Nature* magazine.

In 2013 she visited the Oregon Coast, stopping in Seal Rock for a look at local geological features, including the sea cliff and buried forest remnants near Deer Creek, where the above photo was taken.
V. OTHER COASTAL BASALTS

As at Seal Rock, the basalts at Yaquina Head and Cape Foulweather, formerly called Cape Foulweather Basalt, were part of the Gingko flow of the Frenchman Springs Basalt, which was a part of the Wanapum Member of the Columbia River Basalts. At Yaquina Head the lava was probably a subaerial flow that also encountered water. The lava was quenched (cooled quickly) and fragmented; the round cobbles on the cobble beach are wave-polished remnants of that quick cooling. The lower quarry is a good place to view a cross section of a lava flow. A complete description of the geology of Yaquina Head can be found in Mardock, 1994.

Photo 60. Basalt near the lower quarry at Yaquina Head.

Photo 61. Pillow basalt revealed at low tide in Depoe Bay.

Depoe Bay has two separate flows of the Columbia River Basalt Group. The earlier was Grand Ronde Basalt, which lies along the bay, under Highway 101 and at the entrance to the inner harbor. It is known for its pillow lava, an indicator that the lava entered water. The Gingko flow
came about 100,000 years after the Grande Ronde basalt; it forms the outer rocks at South and North Points in Depoe Bay and at Government Point at Boiler Bay State Park. A sedimentary layer called Sandstone of Whale Cove lies between the two flows at some locations (Snavely and others, 1976c).

**Yachats Basalt**

Between the basement rock of the Coast Range and the coastal basalt of the Columbia River Basalt Group is a series of volcanic rocks in the Coast Range of an intermediate age. It includes Yachats Basalt and Cascade Head Basalt on the central coast, and the Tillamook Volcanics and Grays River Volcanics to the north. They are about 36-32 million years old, from the late Eocene. Associated with this magmatism are intrusive sills of nepheline syenite and camptonite that cooled below the surface of the earth (Oxford, 2007). This volcanic series is an anomaly; there is usually no magmatism between a subduction zone and its volcanic arc, in this case the volcanoes of the Cascade Mountains. More on this later (p. 46).

Yachats Basalt was mainly a subaerial flow extending from the south shore of Alsea Bay to Heceta Head and nearby Sea Lion Point (Map, Figure 9). It forms the beautiful headlands and rugged coastline south of Yachats.

![Photo 62. Yachats Basalt south of Sea Lion Point.](image)

Along the beach at Heceta Head Lighthouse State Park there are rounded basalt boulders, an indication that the basalt was reworked by water after being laid down. Near here the basalt mingled with marine sandstone that includes fossil mollusks (Lund, 1971).

Near Tenmile Creek the Yachats Basalt extends as far inland as Klickitat Mountain and is up to 2,000 feet thick. At the northern and southern ends of the formation it is thinner, about 600 ft. It consists of basalt, breccia, and some pillow basalt near Heceta Head, where the flow met water (Snavely and MacLeod, 1974). Along the rocky shore between Yachats and Big Creek in Lane County are many dikes from a few inches to three feet wide (Photos 63, 73).
FIGURE 9. MAP OF YACHATS BASALT

Distribution of Yachats Basalt and “unnamed basaltic sandstone,” later mapped as basalt. Dark spot at Blodgett Peak is nepheline syenite, a related igneous rock. Abridged from Snavely and MacLeod, 1974.
Yachats Basalt is highly variable in appearance. Some is porphyritic, meaning that it has at least two different grain sizes (Photo 78). Easily visible with the unaided eye are lath-shaped phenocrysts of plagioclase, a whitish feldspar mineral (Photo 83). The presence of phenocrysts, which are conspicuous crystals in a fine-grained matrix of igneous rock, together with the wide range in appearance and the numerous dikes suggest that the magma was differentiated before it was extruded (Snively and MacLeod, 1974).

At Neptune State Park, Strawberry Hill Wayside and the headland near Bob Creek, some of the basalt is scoriaceous or cinder-like, with many small vesicles formed by escaping gas bubbles (Photo 76). Several dikes are present at each of these locations. Breccia is also present, some of it reddish or purplish from oxidation (Photo 75). Small round vesicles filled with zeolites (Photo 80), a group of hydrous aluminosilicate minerals, can be seen in the basalt near Big Creek south of Yachats and also at Eckman Quarry in Waldport.

Walking along the 804 Trail in Yachats near the Fireside Inn, one sees a change in the character of the basalt, from dark, massive blocks and boulders to larger, brown, gritty rocks that form gently sloping platforms. The brown rock was originally mapped as basaltic sandstone (Figure 9). The designation was changed to Yachats Basalt when the USGS map was published in 1976. The brown rocks on the northern part of the trail are weathered basalt made up of many small fragments but they are igneous rock, not sedimentary (Snively and others, 1976a).

A similar texture of weathered basalt can be seen in Photo 64 in a rusty red oxidized layer about 12 inches thick located at Strawberry Hill; it can be reached by following the stairs and trails from the parking lot to the shore. Here the lava likely flowed over a pocket of wet sand. The layer visible just above the sand is the reddish weathered basalt, the lowest of the igneous layers. Above that is a scoriaceous layer that represents the base of the intact flow. Atop that lies the dark massive main portion of the flow. The colorful layers of sand and oxidized basalt do not
extend very far horizontally, suggesting that the wet sand beneath the lava was not extensive (Ore, 2013).

![Photo 64. Colorful banding at Strawberry Hill where lava flowed over a small area of wet sand.](image)

**Other Deposits.** In a few locations such as in Yachats and from Bray Point to Stonefield Beach there are marine terrace deposits atop the basalt that provide level ground. At other places, such as Carl Washburne State Park and just south of Cape Perpetua, dune sand is present. (Lund, 1971). Cobble layers are sometimes seen in the cliff along beaches south of Yachats. At Neptune the cobbles are all of similar size, indicating they were deposited by ocean action. Just south of Big Creek, the cobbles vary in size, indicating that they were transported by the river and are part of an alluvial fan conglomerate topped by a soil layer (Photo 65). The sea level then rose and deposited a layer of sand atop the alluvial fan (Ore, 2013).

![Photo 65. Ocean sand atop the alluvial fan conglomerate north of Muriel Ponsler State Wayside.](image)
Tectonic Setting

Both uplifting and subsidence of the land probably occurred around the time that the Yachats Basalt was extruded. The basalt is underlain by marine sandstone of late Eocene age (Tyee and Nestucca Formations), and overlain by marine siltstone and basaltic sandstone of similar age, including again the moderately deepwater Nestucca Formation at some locations. This suggested to the geologists who mapped the flows that local uplift preceded the Yachats Basalt flows and that local subsidence followed (Snavely and MacLeod, 1974).

Origin of Yachats and Cascade Head Basalt

Cascade Head Basalt is similar to Yachats Basalt in age. It is a slightly alkaline basalt. It consists of submarine and subaerial flows that most likely erupted during the initial phase of shield volcanism, with Yachats Basalt being the more voluminous, middle phase (Perry, 2007).

The current hypotheses about the origin of these basalts require a brief mention of the history of the Cascadia Subduction Zone. The Juan de Fuca plate, which at present lies off the coast of Washington and Oregon (Figure 15), is only a small remnant of a much larger plate called the Farallon plate, which had a role in the formation of the Coast Range. About 60-50 million years ago when the subduction zone was far to the east, volcanic islands formed near the coast on ocean crust of the Farallon plate, and were moved along with it as it converged with the North American plate. The volcanic islands, too large or thick to be subducted under North America, became accreted instead, forming the Siletz River Volcanics (Siletzia Terrane), the basement rock of the Coast Range, which ranges from 25-35 km in thickness (Trehu and others, 1994). One geologist has referred to this terrane as a captured island chain (Duncan, 1982).

Attachment of this huge mass to North America required a reorganization of the plates in this area, with a new subduction zone forming off the western edge of the accreted terrane, not far from its present location.

After the accretion, the Farallon plate was separating at its northern edge from another plate called the Kula, which was being pushed toward Alaska as the two were forced apart at the spreading ridge, where magma rises from the mantle to form new crust. With the spreading ridge perpendicular to the North American plate as it was forced underneath, the Farallon-Kula plates kept moving apart even as they passed under the edge of the North American plate. This resulted in an area essentially without a strong crust. This is called a slab window. Such an area of weak crust with molten magma near the earth’s surface can lead to volcanism where it would not ordinarily occur, which is one hypothesis for the anomalous basaltic series in the Coast Range that includes Yachats and Cascade Head (Thorkelson, 1996; Breitensprecher and others, 2003).

Hot Spots and Mantle Plumes

The other hypothesis concerns a mantle plume and hot spot. A hot spot is an area of volcanism such as the Hawaiian Islands, not connected with a tectonic plate boundary. A plume is an upwelling of especially hot molten rock from deep within the earth’s mantle that results in a hot
spot. In the North American west, volcanologists believe that a hotspot in southeastern Oregon was the source of the Columbia River and Steens Mountain Basalts (Hooper and others, 2007). After causing those huge flood basalts, the hot spot, while still in a fixed location below the westward-moving North American plate, left a “track” across Idaho in the form of the calderas of the Snake River Plain. The hot spot is now below Yellowstone National Park where it is the source of volcanism and geothermal activity.

How does Yachats basalt relate to this hot spot? The second hypothesis has been controversial but it hasn’t gone away since first put forth by Duncan in 1982. It suggests that the clockwise tectonic rotation of the Coast Range resulted in a spreading and weakening of the crust that may have initiated an upwelling from the earth’s mantle, an upwelling that became a plume. Geochemical analyses of the Yachats and Cascade Head Basalt indicated that the magma formed at great depths in the earth, about 70 to 160 km. This suggested to one group of scientists that the Yachats and related basalts might actually record the initiation of a hotspot, possibly the Yellowstone hotspot (Mitchener, 1998; Parker and others, 2010). Another view is that Yachats and related basalts happened after the newly accreted northwest corner of Oregon (the Siletzia Terrane) drifted west across an existing hot spot, triggering huge eruptions of lava that built up along the coast (DOGAMI, 2007).

“The history of the earth may be written in rock, but history is not coherent on a geologic map, which shows a region’s uppermost formations in present time, while indicating little of what lies farther down and less of what is gone from above…To this day, in other words, there remains in geology plenty of room for the creative imagination.” (McPhee, 1998)
PHOTO SECTION: VIEWS OF YACHATS BASALT 1

Photo 66. A pocket beach surrounded by basalt south of Heceta Head.

Photo 67. Basalt on the face of Cape Perpetua with *Sedum, Baccharis*, and grasses.

Photo 68. Rounded basalt rocks at Heceta Head were reworked by water.

Photo 69. Rich lichen growth on basalt near Bob Creek.

Photo 70. Sea cave at the shore near Heceta Head.

Photo 71. Nepheline syenite, an intrusive igneous rock at Blodgett Peak.
VIEWS OF YACHATS BASALT 2

Photo 72. A wave-cut trench at Neptune State Park, probably formed at a fracture in the rock.

Photo 73. One of many basalt dikes between Yachats and Tenmile Creek.

Photo 74. Salt crystals on the basalt platform near the shore at Neptune.

Photo 75. Breccia with an oxidized matrix at Neptune State Park.

Photo 76. Oxidized, scoriaceous basalt at Neptune State Park.

Photo 77. Remnant of basalt shore platform on the beach at Neptune.
VARIATIONS IN YACHATS BASALT

Photo 78. Porphyritic basalt has at least two different grain sizes.

Photo 79. Aphanitic basalt has no visible grain.

Photo 80. Zeolites in basalt from Eckman Quarry in Waldport.

Photo 81. Beach rock with phenocrysts, from south of Yachats.

Photo 82. Nepheline syenite from Blodgett Quarry is not a basalt, but a related igneous rock formed from magma.

Photo 83. Lath-shaped phenocrysts of the feldspar mineral plagioclase in Yachats Basalt.
VI. PALEONTOLOGY

Seal Rock was the site of some important discoveries in marine mammal paleontology due to a gifted young fossil finder named Douglas Emlong. In 1964 he found a complete Oligocene whale skeleton north of Seal Rock State Park that possessed both baleen and teeth, different from any other fossil known at that time. The find seemed so significant that USGS geologists and a paleontologist from the University of Oregon helped him to write and publish a 50-page description and analysis of his discovery (Emlong, 1966). He was 24 years old at the time.

Two other Emlong finds at Seal Rock were especially significant: a new species of *Behemotops*, a four-legged hippopotamus-like herbivorous mammal called a desmostylian, now extinct, that grazed in shallow water; and a new ancestral pinniped species of the genus *Enaliarctos*, found between Seal Rock and Ona Beach, that helped to clarify the evolution of sea lions and related mammals (Orr and Orr, 2009; Berta, 1991).

Sea lions are thought to have evolved from a bear-like ancestor. In the early Miocene there existed a sea mammal called an “oyster bear” (*Kolponomos*) that specialized in diving for mollusks, prying them off rocky substrates and crushing the shells with stout teeth to extract the meat. Emlong discovered the back portion of a skull near Newport in 1969, which he was unable to identify at the time. He found the corresponding cranium and jaw bone eight years later, and when he put them together was able to recognize it as *Kolponomos* from a description published in 1960 of a similar find on Washington’s Olympic Peninsula. This was an example of what his mentor at the Smithsonian called his “uncanny, unrational” gift for locating and identifying fossils (Wallace, 2007).

Emlong’s collection was sold to the Smithsonian Institution in 1967. It weighed 40,000 pounds and filled two moving vans. According to Emlong’s locality notes (1967), the majority of the 260 fossils in the collection were found in the Astoria Formation north of Newport. A total of 59 were collected in the Seal Rock area, including single bones or partial skeletons from porpoises (31), whales (10), desmostylians (6), sea lions (6) and unidentified (6).

Other collectors have looked for marine mammal fossils in the Seal Rock area with less success. Harry Fierstine of California Polytechnic State University discovered a late Oligocene billfish, or blochiid, from the Yaquina Formation south of Ona Beach, a first record for a blochiid from a deposit bordering the Pacific Ocean (Fierstine, 2001).

In February 2012, two paleontologists and an artist searched for vertebrate fossils in the areas where Emlong made some of his most notable finds, including Seal Rock, where they “didn’t find a damn thing” (Boessenecker, 2013).

Luck and timing can be important factors in fossil finding. Kent Gibson of Newport found his first fossil at Ona Beach 17 years ago, when he picked up a rock to toss for his dog to fetch (Photo 84). It turned out to be a partial skull of a porpoise or dolphin. Since that time he has accumulated a notable collection of fossils, including marine mammals. Most of his specimens were from the Astoria Formation north of Yaquina Head, including 7 of his best specimens that were sent to the Smithsonian Institution in 2013.
Salmon and other anadromous fish have a very sparse fossil record, with none known from Lincoln County. There is evidence that salmon ancestors date back to the late Miocene in some locations on the West coast, including *Smilodonichthys*, the “saber-toothed salmon.” It was more than twice the size of the largest living Pacific salmon species.

There is little or no fossil record from the time of the last Ice Age of plants and animals occupying the Coast Range or the extensive Oregon coastal plain that is now mostly under water. In the Willamette Valley during this period, mammoths, mastodons, bison, horses and ground sloths roamed, as evidenced by fossil remains found in Woodburn, Tualatin and Hillsboro (Gilmour, 2011). During the time when the large mammals began to die out, around 12,900 years ago, humans are likely to have been present.

The reason for extinction of megafauna in the Willamette Valley and elsewhere is not certain. At that time, forests in the western Oregon were increasing as the climate changed (Worona and Whitlock, 1995), and human hunters were present. Both have been suggested as contributing to the extinction, with climate change probably having greater force by changing the flora and the food supply.
About two dozen scientists from around the world have studied the amazing fossils collected on Pacific beaches by a young man with an unusual talent and an almost obsessive interest in fossil finding. Highly intelligent but emotionally troubled, Doug Emlong taught himself about fossils and became an avid collector as a youth living in Gleneden Beach, OR. He soon specialized in marine mammals, amassing a collection with many previously unknown species.

On the Oregon Coast the best fossil hunting occurs after winter storms wash away sand to expose bedrock in the intertidal zone. Emlong spent long days soaked to the skin, chipping fossils from rock with a heavy hammer as waves thundered nearby, then carrying heavy loads up from the beach. “It would probably seem to most people that I go to a lot of useless risk and work hunting fossils, but there are moments of tremendous inspiration and thrill that make up for the fatigue,” he wrote.

The photo above shows Doug Emlong at his home in Gleneden Beach where as a young man he sorted agates and chipped fossils. He stored tons of specimens beneath the deck, according to his mother, Jennie Emlong. He set up a small private museum for his specimens, which was not very successful.

He was encouraged by scientists, one of whom helped him sell his collection to the Smithsonian. Emlong continued to find fossils for the institution, which supported his work with small grants. In his search for marine mammal fossils, he also uncovered nearly 50 species of plant fossils from the Yaquina Formation near Newport.

Although he never held a full time job, Douglas was also an amateur painter, musician and writer. He spent the little money he earned from fossils trying to get his work published.

Eventually, priorities changed at the Smithsonian and grant money for fossils became unavailable. Emlong’s fossil finding trips were less successful, and no longer gave him as much relief from emotional turmoil as they once did. His last years were dominated by depression; he was unwilling to seek medical help despite the urging of his mentor at the Smithsonian and his mother.

He died in 1980 at the age of 38 from a fall off the 500-foot cliff at Otter Crest; it was ruled a probable suicide.

One paleontologist wrote of him, “Douglas Emlong’s Promethean prowess in the discovery of unprecedented vertebrate fossils, alike in beds where many, few, or no collectors preceded him, is well known to specialists having personal knowledge of his activities” (Domning et al, 1986).

Another scientist wrote, “This species [Enaliarctos emlongi] is named in honor of Douglas Emlong for a lifetime devoted to the collection of fossil marine mammals from Oregon and his recognition of their value to science.” (Berta, 1991)

Photo of Douglas Emlong courtesy of The Smithsonian Institution.
WHAT’S THE DIFFERENCE BETWEEN WEATHERING AND EROSION?

Weathering involves two processes that often work in concert to decompose rocks. Both processes occur in place. No movement is involved in weathering. Chemical weathering involves a chemical change in at least some of the minerals within a rock. Mechanical weathering involves physically breaking rocks into fragments without changing the chemical make-up of the minerals within it. It’s important to keep in mind that weathering is a surface or near-surface process…

As soon as a rock particle (loosened by one of the two weathering processes) moves, we call it erosion or mass wasting. Mass wasting is simply movement down slope due to gravity. Rock falls, slumps, and debris flows are all examples of mass wasting. We call it erosion if the rock particle is moved by some flowing agent such as air, water or ice.

So, here it is: if a particle is loosened, chemically or mechanically, but stays put, call it weathering. Once the particle starts moving, call it erosion.

(Quoted from US Geological Survey, Geology in the Parks, 1999).

Visible examples of weathering

In this area, salt spray, wind, rain and plants all contribute to weathering of rock. Honeycomb weathering, also referred to as alveoli or tafoni (Italian for honeycomb), is often found at ocean shores. Repeated wetting and drying, wave sluicing and salt are all thought to contribute to pitting of sandstone through physical forces and weakening of the natural cement in the stone. Geologists are not sure why it happens to some sedimentary rock layers and not others, or why the ridges between the holes remain intact. Other fine grained rocks including basalt can show superficial pitting (Bird, 2008).

Photo 86. Honeycomb weathering of sandstone south of Ona Beach.
Local examples of erosion

Erosion of basalt sea stacks often occurs after iron oxidizes in fine cracks, and a chunk of rock eventually falls away. One local resident described spending time atop Elephant Rock during her girlhood, and said that some years ago the basalt that had provided access to the top had eroded away.
Wave action

Erosion by waves can happen in several ways. The mechanical force of waves crashing on rock causes fractures both small and large. The force of the water can compress air into cracks and also scour them with sand and pebbles. This can slowly cause the formation of arches, caves, trenches and blowholes. Joints or fractures in rock are often widened by wave action. Finally, wave action can result in sea stacks, where the most resistant rock remains offshore after the softer rock has eroded (Sloan, 2006).
Agates and jasper

Weathering, erosion and wave action all contribute to agates and jasper being washed up along local beaches. Agates are extremely resistant to erosion and wash up in gravel along rivers and beaches.

Agates and jasper are a type of quartz called chalcedony. Agates differ in color and degree of translucency and are usually banded due to deposition in layers within voids in volcanic rock. They are released when the matrix rock breaks down. Jasper is opaque and usually red, yellow, green or brown. The common red color of jasper is due to iron content in what is basically a chert.

One good source for searching out and identifying agates and jasper, and also fossils and petrified wood, is a web site called Agates at the Oregon Coast. It includes a map of agate areas, photos of fossils, and it also lists additional resources for those interested in finding out more on these topics (Wilson, 2012).
VIII. CHANGING SEA LEVELS

During the history of the earth, the level of the oceans has fluctuated many times. The sea level changes that relate to Oregon’s geologic history happened during the Pleistocene, when four major cycles of glaciation occurred, with ice covering up to 30% of the earth at its maximum. In each glaciation the ice took up immense volumes of water from the oceans. Consequently the sea level regressed during each glacial period and rose (transgressed) during the briefer interglacials.

Around 20,000 years ago during the most recent Ice Age, a continental ice sheet covered much of Canada and dipped into the northern US. It did not reach Oregon, but scoured the Puget Sound area, with one lobe stopping a bit south of Olympia, Washington, and another carving out the Strait of Juan de Fuca.

At the central Oregon coast the sea level dropped nearly 400 ft, leaving the shoreline about 20 miles west of its present location (Davis and others, 2009). This low stand of sea level lasted several thousand years. Otherwise, in the last 80,000 years the sea level fluctuated but generally stayed about 50 meters (164 feet) less than it is at present, as shown in Figure 10. In earlier interglacial periods during the Pleistocene, sea level is thought to have been 3-20 meters (9.8 to 65.6 feet) higher than at present (Poore and others, 2011).

Changing sea levels affected the present coastline by forming marine terraces and “drowning” rivers. Coastal rivers had cut deep channels and formed valleys in the exposed coastal plain when the sea level was low. When it rose again, those river channels and valleys were flooded or “drowned” by rising water and also filled with sediment, creating estuaries and flat-floored valleys. Alsea Bay and Yaquina Bay were formed in this way.

Sediments from the rivers as well as sand from the ocean entered the estuaries where they were mixed in varying proportions. Estuaries are destined to slowly fill with sediments until reduced to a single river channel, though this may take thousands of years (Komar, 1998).

The regressed sea level during the last glacial maximum exposed great expanses of the continental shelf and allowed movement of sediments along the coast. During low sea levels, wind or water currents could move sediments a great distance along the continental shelf since the coastal headlands no longer blocked the flow of sand and silt. With our current high sea level, the Oregon coast is divided by headlands into 18 or so littoral cells and pocket beaches.

The rise in sea level since the last Ice Age has had a tremendous impact on archaeological sites. Because much of the coastal plain where early humans traveled and established camps and villages is now under water, the likelihood of finding archaeological records of the earliest settlers is quite low. Sea level fluctuation also affects interpretation of sites along the present-day coast. For example, sites older than 10,000 years, when the shoreline was far to the west, are not likely to have any shell accumulations because there would have been no source of shellfish nearby (Hall and others, 2004).
FIGURE 10. SEA LEVEL CURVE, LAST 80,000 YEARS

Depth shown in meters at right. Redrawn from Peterson and others, 2007

Photo 93. Rising sea levels after the last Ice Age flooded river channels and created estuaries like Alsea Bay. Photo by Ellis Lampman.
FIGURE 11. BATHYMETRY MAP OFF THE CENTRAL COAST

Contours every 10 m from -130 m to 0, redrawn from Davis and others, 2009.
IX. MARINE TERRACES, SEA CLIFFS, AND SAND

When you stand at the ocean edge and look landward, you can see that the sea cliff or bluff rises almost 40 feet in some places. It displays in cross section the layers of beach and dune sand that cover the land as far as two miles inland. An upland sand sheet like this is lacking on the coasts of Washington or northern California. How was it formed and why here?

The layers of the sea cliff rest upon a platform or marine terrace* of rock that was carved by the constant movement of the ocean. Waves rolling ashore stirred sand and pebbles that scoured the cliff base with an abrasive action, like that of a lapidary tumbler. Over time the rock, in this case sandstone of the Yaquina Formation, was worn away to form a platform or wave-cut terrace at the level of the ocean. Figure 12 illustrates a typical marine terrace and sea cliff.

Atop the sandstone platform there is often, but not always, a small layer of cobblestones, followed by a layer of sand from 3-15 feet thick that shows horizontal bedding. Both are remains of the beach that existed around the time that the platform was cut by waves, before the sea level fell. Higher in the sea cliff are the cross-bedded layers of Pleistocene sand dunes that arrived thousands of years later. The narrow grayish bands separating the dune layers consist of paleosols of silt which were deposited when flat areas or deflation plains created by wind were covered with a layer of silt blowing in off the continental shelf (Peterson, 2013).

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* The term marine terrace is often used to include both the wave-cut platform and the sand layers atop it.

Photo 94. Dune layers and paleosols in the sea cliff near Ona Beach.
FIGURE 12. GENERALIZED SEA CLIFF AND SHORE PROFILE

Based on Lund, 1972, and Clough, 2005.
Photo 95. The gray layer was recently found to be a silt consisting of broken shards of sand particles, not volcanic ash. The distinction was made using a scanning electron microscope (Peterson, 2013).

Photo 96. Wave-cut sandstone platform at Seal Rock St.Pk.

Photo 97. Beach rocks from the Pleistocene cemented by iron oxide atop the wave-cut platform at Seal Rock St. Pk.
Marine terraces develop at times when the sea levels are high. When the sea level regresses, the wearing away at the cliff base stops. However, the land continues to gradually rise, as it has been doing for hundreds of thousands of years. By the time the next period of high sea level arrives, the terrace cut by the waves may have risen many feet. Thus, a series of terraces rise in stair-step fashion along parts of the Oregon coast, with each step marking a high stand of sea level.

Some of the stair-step terraces along the coast are still easily visible at certain headlands such as Cape Arago and Cape Blanco. In our area, though, they are mostly covered with sand and vegetation. The only marine terrace easily seen near Seal Rock is the sandstone platform at the base of the sea cliff (Photo 96). It is mainly exposed along the beach from Quail Street to Ona Beach.

The older, uplifted terraces in our area, now covered with upland sand dunes and vegetation, have been mapped by Kelsey and colleagues (1996). They named six marine terraces on the central Oregon coast, one north of Yaquina Bay and the five shown in Figure 13. They agreed with previous estimates that the age of the lowest marine terrace at the base of the sea cliff south of Yaquina Bay is 105,000 years, and that the first inland terrace, now covered, is about 130,000 years old. The next higher terrace was thought to be 200,000 or more years old, and the two highest more than 200,000 years old.

The dunes that covered the terraces were studied extensively by Curt Peterson, a geologist from Portland State University. During a large-scale dune mapping project on the West Coast, the first step was to reliably distinguish in the field the older (Pleistocene) from the younger (Holocene) sands. Pleistocene sands are often partially cemented and layered with bands of windblown silt, wetland peat or other buried soil (paleosols) and iron oxide hardpan. Holocene sands are relatively uncemented. There is usually a paleosol layer separating them from the older sand beneath.

Because the upper limit of radiocarbon dating is about 50,000 years, Peterson and his colleagues used a technique called thermoluminescence dating that determines the age of sand dunes as far back as 100,000 years and more.

Results of local sand cliff dating, from Peterson and others, 2007.

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample site</th>
<th>Depth</th>
<th>Age x 1000 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ona Beach</td>
<td>Base of Pleistocene dune</td>
<td>12.7 m</td>
<td>62.6 +/- 4.1</td>
</tr>
<tr>
<td>N. Beaver Creek Rd. beyond turn to S. Beaver Creek Rd.</td>
<td>Pleistocene dune at road cut, west side</td>
<td>2.5 m</td>
<td>103 +/- 7</td>
</tr>
<tr>
<td>Seal Rock State Park</td>
<td>Top of Pleistocene dune</td>
<td>2.5 m</td>
<td>46.4 +/- 4.1</td>
</tr>
<tr>
<td>Seal Rock State Park</td>
<td>Backshore beach</td>
<td>7.5 m</td>
<td>111 +/- 23</td>
</tr>
</tbody>
</table>
FIGURE 13. MARINE TERRACES OF THE SEAL ROCK AREA

These terraces are covered with soil and vegetation and therefore not visible. Redrawn from Kelsey and others, 1996. Kelsey named the terraces, but those names are not often used. Marine isotope stages (MIS) are more useful because they provide dates and permit correlation to marine terraces in other areas. Both the names and marine isotope stages are shown here.

<table>
<thead>
<tr>
<th>Name</th>
<th>MIS</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wakonda (W)</td>
<td>5c</td>
<td>105,000</td>
</tr>
<tr>
<td>Yachats (Y)</td>
<td>5e</td>
<td>130,000</td>
</tr>
<tr>
<td>Crestview (CR)</td>
<td>6?</td>
<td>Est. ~200,000</td>
</tr>
<tr>
<td>Fern Ridge (FR)</td>
<td>?</td>
<td>Est. &gt;200,000</td>
</tr>
<tr>
<td>Alder Grove (AG)</td>
<td>?</td>
<td>Est. &gt;200,000</td>
</tr>
</tbody>
</table>
By correlating sand age with sea level fluctuations and changes in prevailing winds, Peterson and his colleagues (2007) were able to piece together the following scenario for the upland dune accumulation on the Oregon Coast.

Ocean sand from southern Oregon and northern California was moved northward by ocean currents during the Late Pleistocene, at a time of lower sea levels. When the sand reached the area of the Heceta, Perpetua and Stonewall Banks (see Figure 11), these undersea highlands stopped the northward sand migration and created a huge deposition center. From there, onshore wind moved the sand across the exposed continental shelf in several pulses over tens of thousands of years.

As the wind brought the sand inland, it drifted up into the foothills and covered the marine terraces along with their cobbles and beach sand. It was stopped only by the increasing elevation of the Coast Range and depletion of the sand supply. Much of the sand came ashore further south along the coast to form the large dunes between Florence and Coos Bay. Some of the sand extended north beyond Lincoln City. In our area, the Newport Dune Sheet extends from Cape Foulweather to Cape Perpetua (Peterson and others, 2007).

In the Seal Rock area, the dune field reached inland nearly 2 miles, as far as the Fern Ridge Cemetery. From there, the dunes extended westward across the exposed inner continental shelf to the former shoreline, which sometimes was as far as 20 miles to the west during the last glacial maximum.

Around 18,000 to 15,000 thousand years ago when the earliest humans may have migrated down the coast in boats, they would have encountered a coastal plain that consisted of sand dunes interspersed with broad deflation plains. The dry and cool conditions prevailing at that time would have limited the amount of vegetation growth on the dunes (Peterson and others, 2007).

### Marine Terrace, Sea Cliff and Sand Terms

- **Bluff**—An elevated area more rounded in profile than a cliff, with the rock face concealed by soils and vegetation.
- **Deflation plain**—Flat valley shaped by the wind, behind or between sand dunes.
- **Eolian**—Pertaining to the wind.
- **Holocene**—Interglacial period from 10,000 years ago to the present.
- **Coastal loess**—(pronounced luss or less) Wind-transported silt and clay from the exposed continental shelf.
- **Paleosol**—An old soil layer that has been buried by another geologic layer.
- **Placer**—(pronounced plass-er) An alluvial, marine or glacial deposit of sand or gravel containing a valuable mineral; placer mining is the extraction of gold or other mineral from such a deposit.
Holocene Sand

A second influx of sand in the mid and late Holocene, some 7,000 to 3,000 years ago, brought more sand to the beaches. This time it was waves that transported sand from the offshore deposition center to form beaches near the present shoreline, providing an abundant sand supply for a final push by the wind. At its greatest extent the Holocene sand influx was a smaller event than the Pleistocene dune building, reaching at most only about half as far inland.

So how did Holocene sand get from the beach to the top of the sea cliffs? During a time when sea level was slightly lower and more beach was exposed, the Holocene dunes were higher, forming ramps to the top of the Pleistocene sea cliff around 4,000 to 2,500 years ago. They even covered the basalt headland and associated rocks in Seal Rock.

This may help explain why the archaeological sites around Seal Rock are relatively recent compared to others on the coast. According to archaeologist Jon Erlandson of the University of Oregon, “In contrast to the Seal Rock shell midden, most of the Oregon sea-cliff middens were occupied prior to the onset of late-Holocene dune supply. As the local coastal conditions changed from rocky coastline to broad beaches and then back to rocky headlands, the Native Americans would have changed their shellfish harvest sites or adapted to different food sources.” (Quoted in Peterson and others, 2003).

From Ona Beach to Driftwood Beach, the Holocene sand sometimes occurs as a narrow fringe atop the Pleistocene dunes. South of Driftwood the Holocene sand is more visible, especially where it was deposited up against the older Pleistocene sand, blocking the flow of small streams
to form barrage ponds. Several such ponds are visible where Hwy 101 follows the boundary between the Holocene and Pleistocene sand from around Tawn Mar Drive almost to Alsea Bay.

![Photo 99](image)

Photo 99. This barrage pond along Hwy 101 north of Waldport formed when the Holocene sand influx blocked a small stream.

A few remnants of sand from the Holocene still remain on local beaches today. The low dunes along Alsea Spit and north past Driftwood State Park, and those at the mouth of Beaver Creek are examples.

![Photo 100](image)

Photo 100. Holocene dunes above and below the older iron-stained Pleistocene sand north of Driftwood Beach were once part of a dune ramp that buried the darker layers.
Tombolos

While searching the Web for anything pertaining to Seal Rock’s geology, I came across a paper by an Italian geologist that included a photo taken from Seal Rock State Park along with pictures of several of geological sites in Europe. The Seal Rock photo, taken in 1992, was a view of the beach looking north from the park, with a caption that pointed out the tombolos in the picture. Not knowing what tombolos were, I had no idea that Seal Rock was known for them.

It turns out that they are wave-built ridges or sand spits that connect a small island or a sea stack to the mainland. They form when incoming waves bend around a stack, sweeping sand together from both sides. The name originated in Italy, but they are found in many places throughout the world. A tombolo that is submerged at high tide is called a tie-bar (Bird, 2008).
Sand Mineralogy

Most sand on local beaches is made up of fine grains of quartz and feldspar minerals. They are either transparent or light tan and give the beach its color. There also are small amounts of heavy minerals such as magnetite, chromite, garnet, green hornblende and zircon that can appear as black, brown, green, pink or colorless specks in the sand. Minerals can be concentrated by wave action into black sand deposits on the upper part of the beach (Clemens, 1987).

Some of the heavy minerals originated in the Klamath Mountains of southern Oregon and northern California. Particles were carried to the ocean by rivers, then moved northward by near-shore currents, or littoral drift. As one travels northward along the Oregon coast there are progressively lesser amounts of the Klamath heavy minerals.

Also found on south-central to north coast beaches are grains of augite (pronounced aw-jite) and brown hornblende, washed downstream from volcanic rocks in the Coast Range. The mineral content of sand varies considerably along the Oregon coast, sometime so much that there are distinct changes in mineralogy on opposite sides of headlands (Komar, 1998).

In a study conducted between Cape Meares and Cape Lookout, Jim Young observed three separate colors of sand on the beach: blue-black, brownish and light tan. He studied each with a scanning electron microscope and x-ray powder diffraction. The major mineral in the blue-black sand was ilmenite; it had very small, smoothly rounded particles. The brownish sand contained mainly augite, diopside, pargasite, and magnesiohornblende. The light tan and colorless particles were mainly quartz and feldspar, which are the largest and lightest in weight of all the particles (Young, undated).
Gold Mining and Mercury Contamination

Small amounts of black sand on area beaches were thought to contain very tiny amounts of gold particles, about 1 ppm, along with the other heavy minerals (Snively and MacLeod, 1971). Black sand deposits are more common on the south coast between Cape Arago and Cape Blanco, where the placer deposits were mined for gold in the 1800s, mainly on old marine terraces. Wind and ocean currents brought small amounts of the black sand northward. In Lincoln County mining was attempted along a few creeks, notably Collins Creek. Another black sand location in our area is the small unnamed stream at the Curtis Street beach access.

Placer mining of sand sometimes involved the use of mercury to help extract the gold. Mercury was found by a private citizen in 1999 on the beach near Seal Rock State Park at Hill Creek west of Hwy 101. It was reported to the Oregon Department of Environmental Quality (DEQ).
Around 5 gallons of mercury-contaminated soil and cleanup debris were removed in 1999. The source of the mercury was unknown. DEQ reported that the mercury seemed to be coming from the vicinity of fill material under the highway. Gold mining was one of three possible origins of the contamination; the others were road embankment fill material or incidental dumping (Maynard, 2001).

A second public complaint led to testing of shellfish at Seal Rock, which were found to be within acceptable limits for mercury. In February 2002, DEQ estimated that 8 cubic feet of soil with visible mercury contamination remained. In June of that year, a cleanup firm removed approximately 55 gallons of contaminated soil and cleanup debris (DEQ Environmental Site Cleanup Information Database).

Iron-Bearing Films at Coastal Seeps

One day, walking the path down to the beach, I literally stumbled into a fairly common but little understood coastal phenomenon. In ephemeral pools at seeps near the beach, there is sometimes an iridescent or “oily” film on the water. It occurs here because of the abundance of soluble iron in coastal groundwater. Often there is a rusty-orange flocculent present in the same location as the film.

The film occurs naturally, and is neither a biofilm nor an oil. It forms in minutes to hours via rapid oxidation of iron at the air-water boundary. The film breaks up into platelets when disturbed by wind or rain. It was given the name “Schwimmeisen”, which means floating iron or swimming iron. From samples collected at Seal Rock State Park and Driftwood State Wayside, it was determined that the film formed by an abiotic process, although iron-oxidizing bacteria were present in the orange flocculent at the bottom of the pools (Grathoff and others, 2007; Easterly, 2005).

Photo 106. Iridescent film of Schwimmeisen or floating iron at a seep in Seal Rock State Park
X. BURIED FORESTS

The dance of wind, moving sand and rising seas has never been simple or unidirectional. One mystery on Oregon beaches has been the origin of rooted tree stumps that become visible especially in winter when beach sand is moved offshore during storms.

Local geologist Roger Hart was fascinated by the buried forests that appeared along the Oregon coast in areas where the sea cliff is actively eroding, especially after the winter of 1995 when some previously unknown buried trees were exposed. Over several years he documented a total of 520 rooted stumps and their associated soils and leaf litter (Hart and Peterson, 1997).

The rooted stumps and associated soils were remnants of a series of forests that extended farther seaward than today’s shoreline. Hart concluded they must have grown on a shore platform after the shoreline regressed and allowed formation of a soil layer that would support tree growth. The buried forests were determined to range from around 5,000 to 1,200 years old at different locations. Therefore, intermittent pulses of incoming sand must have covered and preserved individual tracts of forest over this period of years. The same pulses of sand may have formed dune ramps to the top of the sea cliff which were later truncated by a rise in relative sea level. Figure 14 diagrams the steps in burying, preserving and then revealing the ancient forests.

The largest rooted stumps found on coastal beaches lived to be about 200 years old. In some groups of trees there was an influx of sand after soil began to form, indicating a temporary reversal of conditions. A few of the forests were buried while the trees were still young.

Rapid burial by sand was the key factor in killing the forests (Hart and Peterson, 2006). Downdropping from a mega-earthquake (coseismic subsidence) did not have a role in burial or preservation of the forests, because subsidence would have eroded the sand and not increased it (Peterson, 2013). However, it is possible that localized vertical tectonic changes may have been one of several factors in reemergence of the stumps.

Locally, two of the rooted stumps have been exposed intermittently near Deer Creek since 1982. Two additional stumps nearby are rooted in the bank at the top of the beach. Hart discovered that the soil layer beneath those stumps continued north to the top of the sea cliff and then all the way to Seal Rock State Park. He dated the wood from one of the stumps at 4,338 years old, compared to an average of 3,070 years for all samples along the coast. A sample taken near Quail Street was determined to be 3,100 years (Hart and Peterson, 2006). The authors concluded that the emergence of buried forests reflected a current trend of episodic sand loss by wave erosion along our beaches, possibly a result of global climate change.

In another type of buried forest, tree trunks were preserved by a catastrophic landslide in a coastal stream bank between Yachats and Cape Perpetua. The wood was determined to be at least 50,000 years old (Smyth and Hart, 2005).

Lastly, a recent study of the Big Stump visible during the past century on the beach south of Waldport found it to have died 1,820 to 1,720 years ago; it may have been part of a disjunct population of coast redwood, *Sequoia sempervirens* (Gavin and others, 2013).
Photo 107. A rooted stump visible at Curtis St. beach since 1982.

Photo 108. This stump, originating in the base of the bluff north of Deer Creek, was radiocarbon dated at 4,338 years old.
FIGURE 14. CONCEPTUAL MODEL: HOW BURIED FORESTS WERE PRESERVED

Redrawn from Hart and Peterson, 2006.
Roger Hart

A field geologist who lived in Seal Rock, Roger is remembered fondly by many friends and colleagues in Oregon as a person who cared passionately about the coast and was always willing to share his knowledge.

He spent many days in the field recording and carbon dating the buried forests which were exposed mainly after 1995. He published several scientific articles and developed a conceptual model to explain how it happened that huge trees once grew at present-day coastal beaches.

Roger’s early years included the study of geology and geophysics at Yale and Tufts, and climbing mountains. He was a member of the first expedition to climb the north face of Mt. Everest without oxygen. He received a Max Planck fellowship, was a visiting scientist in India, and had a glacier named after him in Antarctica. His profession and love of climbing and travel took him to over 40 countries.

Prior to his death in 2011 he was employed by the Oregon Department of Geology and Mineral Industries (DOGAMI) as a field researcher surveying and mapping the movement of sand and rock along the coast. Other professional employment included studying marine hydrothermal vents while a research professor at Oregon State University, and teaching physical sciences at Oregon Coast Community College.

Roger was a man of many talents, respected for his professional work and for his activism in local and regional environmental issues. His dedication and willingness to share his expertise are remembered by many members of CoastWatch and by participants in the coast conferences sponsored by Oregon Shores Conservation Coalition. Others remember fascinating discussions with him over the salad bar at Oceana Natural Foods.

Roger was a gifted writer who told how his adventures in remote places led to an exploration of the nature of consciousness in his book *The Phaselock Code*, published in 2003. He was also a musician and photographer.

Some testimonials to Roger’s memory: “If you walked a beach with Roger, you never saw it again in the same light,” “Oregon has lost one of its truly memorable characters,” and “His expertise and humanity will be missed.”
XI. EARTHQUAKES, TSUNAMIS, SUBSIDENCE, UPLIFT

The Cascadia Subduction Zone (Figure 15) off the Pacific Northwest coast, where the Juan de Fuca plate is sliding under the North American plate, causes a massive earthquake every few centuries. Scientists didn’t discover this until the 1980s; previously people assumed that because we didn’t have frequent smaller earthquakes like California, this area wasn’t earthquake prone. A report from the southern Washington coast began a change in awareness in the Northwest that continues to grow.

Once the initial evidence for a megaquake was published (Atwater, 1987), geologists accumulated more data indicating that large earthquakes happened on the Oregon coast from 300 to 1,000 years apart.

A book called *Cascadia’s Fault: The coming earthquake and tsunami that could devastate North America* by Jerry Thompson (2011) gives an excellent account of the geological discoveries that led scientists to understand the reality of great earthquakes and locally generated tsunamis. His description of what a magnitude 9.2 earthquake would be like could help motivate citizens and communities to become more willing to prepare.

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**Earthquake off the Coast!**

On the night of January 26, 1700, at about 9:00 pm, the earth shuddered in a magnitude 8 or 9 earthquake. The land in the Pacific Northwest suddenly dropped down as much as several feet in some coastal areas. Within 15-20 minutes a large tsunami generated by the earthquake crashed ashore, inundating low-lying areas up to a mile inland, and even farther where rivers and streams provided a channel. The tsunami from the 1700 earthquake spread west across the Pacific where it was recorded in Japan, which is how we know the date and time of the event. Native American oral history from the coast of southern Oregon and northern California contains accounts of the disaster, which destroyed villages, altered the estuaries and disturbed traditional fishing and shellfish areas. The survivors, with their winter’s food supply destroyed, had to cope with loss of family, locate other survivors, find subsistence and rebuild villages in a changed land.

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The Cascadia Subduction Zone is responsible for gradual uplift of land between quakes followed by rapid subsidence when the land suddenly shifts as enormous pressure is released during a quake. The amount of subsidence varies along the coast; in South Lincoln County it can range from 0.5 to 1.0 m during great earthquakes. It ranges up to 1-1.5 m in southern Oregon and in Clatsop County. Uplift rates also vary along the Oregon Coast. In some areas land is rising at a rate slightly faster than sea level rise. On the central coast the sea is rising faster than the land, resulting in very gradual loss of land to the ocean. For our part of the coast, then, continued erosion of the beach and sea cliff is the norm (Komar, 1998).
FIGURE 15. CASCADIA SUBDUCTION ZONE: MAP AND EARTHQUAKE TIMELINE

CASCADIA EARTHQUAKE TIMELINE

Numbers are years before the present. Bold lines = earthquake of Magnitude 9+, Fine lines = Magnitude 8+. Timeline based on dating of submarine landslides by Chris Goldfinger of OSU and diagram by Ian Madin published by DOGAMI, 2010.
Finding Evidence of Past Earthquakes and Tsunamis

At Alsea Bay, Curt Peterson and Mark Darienzo extracted long soil cores from the marshlands just east of Waldport between Bayview and Eckman Lake. A clear pattern was revealed. Marsh soil gradually accumulated for several centuries from silt and decayed vegetation. Then the soil was abruptly covered with sand, suggesting that the land subsided during an earthquake and a tsunami had washed in a layer of sand from the beach. The beach origin of the sand was determined from grain shape and mineral composition, eliminating flood or other upriver occurrences as the source. Radiocarbon dating revealed that the long-term average recurrence of earthquakes in Alsea Bay was about 500 years, roughly the same as reported from other Oregon estuaries (Peterson and Darienzo, 1991). Evidence of large earthquakes has also been found at Beaver Creek (Peterson and others, 2010) and smaller creeks between Newport and Yachats (Peterson and Cruikshank, 2011).

Earthquakes in the past have also left signs in the deep ocean sediments off the Northwest coast. Turbidites are sedimentary deposits that occur as a result of turbidity currents or underwater landslides. One researcher dated a series of turbidites using Mt. Mazama ash as a marker, and discovered that 13 of the post-Mt. Mazama underwater landslides happened almost simultaneously at widely separated sites. He hypothesized that they were triggered by a subduction zone earthquake (Adams, 1990).

Chris Goldfinger of Oregon State University has studied the turbidites extensively. His recent summary of 13 years of research listed 19 earthquakes of Magnitude 9+ that occurred in the last 10,000 years along the length of the Cascadia Subduction Zone, plus 22 slightly smaller—perhaps 8.0—that happened mostly at the southern end of the zone. A timeline of these quakes is shown at the bottom of Figure 15. He then compared earthquake evidence from turbidites with tsunami marsh deposits and found a reasonably good coincidence. He considers the two methods of dating paleoseismic events as complementary; the onshore record provides better accuracy for the more recent events while the turbidite record extends farther back in time (Goldfinger and others, 2012).

Soft-sediment deformation is another sort of evidence of paleoearthquakes. It can occur on land during seismic liquefaction, when sand is saturated and can move like a fluid. The shaking during an earthquake can cause cracks in the non-liquified earth above the sand, which then allow penetration of the liquified sand. If the liquified sand reaches the surface it forms a sand boil, also called a sand volcano. When the liquified sand does not reach the surface, it can move into a soil layer and form a sill. One such sill can be seen in an earthen bank near Deer Creek (Photo 109). A feature such as this can give information about seismicity in regions where large earthquakes happen infrequently.

The last subduction zone earthquake off the Oregon Coast occurred over 300 years ago. The next great earthquake could happen any time. A Magnitude 9 quake will likely result in slip movement of 40-60 feet along an area 600 miles long and over 60 miles wide (DOGAMI, 2012).

The most recent maps and evacuation guides for Oregon along with information on preparing for earthquakes and tsunamis can be found at www.oregongeology.org. Tsunami inundation maps
for the Oregon coast were released in 2013 that incorporated lidar mapping technology; lidar is similar to radar but uses lasers to accurately map shoreline and nearshore areas. Also included in developing the maps was new information learned from the earthquake and massive tsunami that struck Japan in March of 2011. Also on the DOGAMI web site are maps showing local areas of landslide and erosion danger, soil stability, and expected earthquake shaking.

Photo 109. Soft sediment deformation shows evidence of an old earthquake near Deer Creek. The quake caused liquefaction of sand which was forced upward to form a layer within the dark soil.

Where geology is concerned it helps to know what you are looking for… I had read a paper by geologists Roger Hart and Curt Peterson that mentioned an example of soft sediment deformation along the bluff near Deer Creek. I looked for it several times without success, finally concluding that vegetation must have grown over it during the time since the paper had been written. When Curt Peterson made a local stop during a visit to the coast, I was fortunate to have him point out the very structure I’d been looking for, in plain sight, not blocked by vegetation. I must have walked by it countless times. Sometimes it takes a geologist’s eye…. 
XII. THE LAST HUNDRED YEARS

One human lifetime is not long enough to experience the extent of the changes taking place at the shoreline. Most of us don’t remember that coastal erosion claimed more than a dozen homes in Newport in 1942, and that a large condominium structure built next to the slide had to be demolished in 1985 after erosion damaged it (Komar, 1998).

In a few years a river mouth can be relocated, a sand spit breached and a beach formed or lost. A bay mouth and spit can migrate up to 600 feet in several years. El Niño/La Niña storms can cause rip current embayments resulting in 125 feet of beach erosion in one or a few storm cycles (Priest and others, 2004).

For a highly readable account of ocean forces and the effects on the built environment in the last hundred or so years, see Paul Komar’s *The Pacific Northwest: Living with the shores of Oregon and Washington*. Duke University Press, 1998.

Effects on local geomorphology from Euro-American settlement go back almost a century and a half. Homesteaders began draining marshes along Beaver Creek and installing tide gates along Alsea Bay that changed wetlands to agricultural fields. Later, industrial-scale logging increased flooding and landslide danger, with more sediment washed into local streams and rivers.

Since the 1920s, episodes were reported in local newspapers of high water or flooding on Beaver Creek after storms. In 1947 the Lincoln Grange requested help with flood control, and some blasting was done at the mouth of Beaver Creek by the Port of Newport. In November of 1948 the creek flooded again due to sand and debris accumulation after a storm. The lumber mill near mouth of Beaver Creek was forced to close when their mill pond and the river overflowed; this time the company dynamited the channel. Further episodic flooding and requests for better drainage continued at least through 1952 (Bayer, 1994).

Beginning around the 1960s, a global warming trend began. Significant erosion along the coast occurred after intense storms. It became obvious that homes and highways were constructed too close to the ocean and in landslide areas. In 1972 severe erosion occurred at Siletz Spit. In 1978 a storm caused the breaching of Nestucca Spit (Komar, 1998).

In 1983 severe storms brought a series of changes to Alsea Spit that were well documented by aerial and ground photos. The channel at the mouth of the Alsea River was deflected northward. The tip of Alsea Spit was eroded away; homes were threatened and damaged. The flood risk to Waldport increased. Tons of rip-rap were placed on the spit in an attempt to protect homes, affecting the aesthetics of the ocean shore (Komar, 1998; Jackson and Rosenfeld, 1987).

Extreme storms that occurred during the 1997-98 El Niño and the 1998-99 La Niña were the largest reported in 25 years (Allan and Komar, 2002). A storm in early March of 1999 caused especially high waves and a storm surge. One result was that flooding occurred in the Beaver Creek marsh that killed a stand of trees on the north side of Beaver Creek road, according to one resident.
Photos 110, 111. Drainage canals and tide gates turned what was once a productive wetland on a former oxbow of the Alsea River into pasture near Bayview.

Photo 112. Dead trees at Beaver Creek marsh killed by flooding after an intense coastal storm.

“In developing the Oregon coast we have made numerous mistakes that have placed homes and condominiums in the path of erosion. Development has been permitted in foredunes of sand spits immediately backing the beach, along the edges of precipitous sea cliffs, and even in the area of the active Jump-Off Joe landslide. Such unwise developments and the accompanying proliferation of seawalls and riprap revetments have progressively degraded the qualities of the Oregon coast that we cherish” (Paul Komar, 1992).
XIII. THE FUTURE

The major influences on the geomorphology of the Oregon Coast during this century and the next are expected to be the acceleration of climate change and the arrival of the next Cascadia Subduction Zone earthquake and tsunami.

Sea level rise along with more intense storms and greater wave heights will increasingly threaten local sea cliffs, beaches, estuaries and local infrastructure. The rise in global sea level is expected to be 3-6 feet by the end of this century or the next. Impacts will vary along the Oregon Coast, with the greatest rise in relative sea level from Florence almost to Astoria where tectonic uplift is not keeping up with the rise in sea level. Increased carbon dioxide in the atmosphere will result in ocean acidification, meaning organisms such as clams, oysters and corals will have difficulty developing their shells (Solomon, 2012).

The maximum significant wave height has increased from about 9 to 12 meters (29.5 to 39.4 feet) in a 30-year period ending in 2005. Rising storm wave heights may be a larger factor in coastal erosion and flooding than will the rise in sea level (Ruggiero, 2012). The effect on Oregon’s sand beaches is that net sand loss will continue, and the wide summer beaches may all but disappear in the next century, exposing the underlying gravel and sedimentary rocks in all seasons (Peterson, 2012a).

Sea cliffs will continue to erode, but at an increased rate: a sea level rise of 3-6 feet could result in 300-600 feet of beach retreat, which will expose sea cliffs and associated sandstone platforms to wave attack and destabilization. Estuaries will see increased river flows in winter, greater flooding and salinity intrusion (Peterson, 2012b).

The last major earthquake on the Cascadia Subduction Zone was 313 years ago. Scientists can’t predict when the next one will happen, only that it will. Megaquakes are not all alike. The event of 1700 was not the largest in the past 10,000 years; a few have been much larger. One lesson learned from Japan’s Tohoku earthquake and tsunami of 2010 is to plan not for the average but for the largest known disaster.

The main message from the scientists is that education and preparedness are crucial. Most people will survive, but we may be on our own for weeks or months. Community preparedness, resilience and self-reliance will be thoroughly tested.

CONCLUSION

The geologic forces we observe and experience on the Oregon coast, while sources of fascination and beauty, are far more powerful than any knowledge that humankind has of them. What we can gain from learning about them is a respect for the earth, appreciation of its mystery, and a willingness to adapt to the earth’s processes. As someone once said, “Humans live on this planet on sufferance of massive forces we don’t fully understand. Our welcome can be withdrawn at any time.”
XIV. REFERENCES


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