

# Seamount Geography

Entry #:	44.35.2
Word Count:	14748 words
Reading Time:	74 minutes
Last Updated:	October 04, 2025

*"In space, no one can hear you think."*

## Table of Contents

### Contents

<b>1</b>	<b>Seamount Geography</b>	<b>3</b>
1.1	Introduction to Seamount Geography . . . . .	3
<b>2</b>	<b>Introduction to Seamount Geography</b>	<b>3</b>
2.1	Defining Seamounts and Underwater Mountains . . . . .	3
2.2	Geographic Scope and Distribution Patterns . . . . .	4
2.3	Importance in Ocean Systems . . . . .	4
2.4	Multidisciplinary Research Approach . . . . .	5
2.5	Formation and Geological Processes . . . . .	5
2.6	Volcanic Formation Mechanisms . . . . .	5
2.7	Plate Tectonic Influences . . . . .	6
2.8	Global Distribution and Classification . . . . .	7
2.9	Ocean Basin Distribution . . . . .	8
2.10	Major Seamount Chains and Provinces . . . . .	9
2.11	Classification Systems . . . . .	10
2.12	Physical Characteristics and Morphology . . . . .	10
2.13	Summit Features and Morphology . . . . .	11
2.14	Flank Structures and Characteristics . . . . .	12
2.15	Ecosystems and Biodiversity . . . . .	12
2.16	Primary Productivity and Food Webs . . . . .	13
2.17	Benthic Communities . . . . .	13
2.18	Fish Communities and Aggregations . . . . .	14
2.19	Biogeography and Endemism . . . . .	15
2.20	Oceanographic Influence and Climate Connections . . . . .	15
2.21	Oceanographic Influence and Climate Connections . . . . .	15

<b>2.22 Human Discovery and Exploration History . . . . .</b>	<b>17</b>
<b>2.23 Early Navigation and Discovery . . . . .</b>	<b>18</b>
<b>2.24 Technological Evolution in Seamount Detection . . . . .</b>	<b>19</b>
<b>2.25 Golden Age of Seamount Exploration . . . . .</b>	<b>20</b>
<b>2.26 Economic Resources and Exploitation . . . . .</b>	<b>20</b>
<b>2.27 Scientific Research Methods and Technologies . . . . .</b>	<b>23</b>
<b>2.28 Environmental Threats and Conservation . . . . .</b>	<b>25</b>
<b>2.29 Fishing Impacts and Overexploitation . . . . .</b>	<b>25</b>
<b>2.30 Mining and Extraction Threats . . . . .</b>	<b>26</b>
<b>2.31 Pollution and Contamination . . . . .</b>	<b>27</b>
<b>2.32 Notable Seamounts and Case Studies . . . . .</b>	<b>28</b>
<b>2.33 Future Perspectives and Research Directions . . . . .</b>	<b>30</b>

# 1 Seamount Geography

## 1.1 Introduction to Seamount Geography

## 2 Introduction to Seamount Geography

Beneath the vast expanse of Earth's oceans lies a hidden landscape of immense proportions—a submerged mountain range system so extensive that it dwarfs all terrestrial mountain ranges combined. These underwater mountains, known as seamounts, represent one of the most significant yet least understood features of our planet's geography. Rising from the abyssal plains to heights that would dominate any continental landscape, seamounts form a global network of underwater peaks that profoundly influence ocean chemistry, circulation patterns, and biological diversity. Despite their ubiquity—with estimates suggesting over 100,000 seamounts rise more than 100 meters from the seafloor—these remarkable features remained largely hidden from human knowledge until the latter half of the 20th century, when advancing technology finally allowed scientists to begin mapping the ocean floor in detail.

### 2.1 Defining Seamounts and Underwater Mountains

The formal scientific definition of a seamount establishes it as an underwater mountain rising at least 100 meters from the seafloor, with a conical or rounded shape that does not reach the ocean surface. This minimum height criterion distinguishes seamounts from smaller features known as knolls, which rise less than 100 meters, while placing them in a distinct category from larger underwater plateaus or banks. The upper limit for seamount classification typically falls around 1,000 meters in height, beyond which features are often termed underwater mountains or seamount chains. Perhaps the most fascinating variation is the guyot—a flat-topped seamount that once breached the ocean surface as a volcanic island before undergoing erosion and subsidence to its current submerged state. The term “seamount” itself entered scientific literature in the early 20th century, derived from the straightforward combination of “sea” and “mountain,” though earlier maritime cultures had their own names for these navigational hazards and fishing grounds. The Hawaiian term “kapa” and the Japanese “kaizan” both referred to underwater mountains long before Western science formally categorized them.

The scale of seamounts varies tremendously, from small conical features just meeting the 100-meter minimum to massive volcanic complexes rising thousands of meters from the ocean floor. The Mauna Kea seamount, when measured from its base on the Pacific Ocean floor, stands over 10,000 meters tall—surpassing Mount Everest in height despite its summit remaining underwater. This vertical dimension represents only one aspect of seamount morphology, as these features typically spread out at their bases with diameters several times their height, creating extensive underwater landscapes that profoundly modify local ocean conditions. The sheer abundance of seamounts has only recently been appreciated, with satellite altimetry and ship-based sonar surveys revealing that they occur in virtually all ocean basins, though with markedly different densities and distributions.

## 2.2 Geographic Scope and Distribution Patterns

Seamounts populate ocean basins worldwide, but their distribution follows distinct patterns that reflect underlying geological processes. The Pacific Ocean contains the overwhelming majority of seamounts, with estimates suggesting it hosts over 55,000 such features—more than half of the global total. This Pacific dominance relates directly to the region's active tectonic history, particularly the movement of the Pacific Plate over numerous mantle hotspots that have generated extensive seamount chains. The Atlantic Ocean contains fewer seamounts but still features significant concentrations, particularly along the Mid-Atlantic Ridge and in regions influenced by hotspot activity such as near Bermuda. The Indian Ocean, while less extensively studied, contains notable seamount provinces including the Ninetyeast Ridge, which extends nearly 5,000 kilometers across the ocean basin.

Latitudinal distribution patterns reveal that seamounts occur at all latitudes, from polar regions to equatorial zones, though certain latitudes display higher concentrations. The band between 20° and 40° latitude in both hemispheres contains particularly high densities, especially in the Pacific where this zone encompasses numerous hotspot tracks. Depth distributions follow predictable patterns as well, with most seamount summits found between 1,500 and 3,000 meters below sea level, though their bases may extend to abyssal depths exceeding 5,000 meters. This vertical positioning places seamounts as important intermediaries between deep-ocean and surface-layer processes, creating unique environments where distinct water masses interact and where biological communities can access enhanced food supplies from both above and below.

## 2.3 Importance in Ocean Systems

The significance of seamounts extends far beyond their impressive physical dimensions, as these features play crucial roles in multiple ocean systems. Through their interaction with ocean currents, seamounts create complex flow patterns that enhance vertical mixing, bringing nutrient-rich deep waters toward the surface and supporting elevated primary productivity in otherwise oligotrophic regions. This current acceleration around seamount flanks can generate Taylor columns—rotating water masses that become trapped above seamount summits, creating relatively stable environments that support distinct biological communities. The enhanced turbulence and mixing generated by seamounts contribute significantly to global ocean circulation patterns, affecting heat transport and the distribution of chemical properties throughout the water column.

Biologically, seamounts function as biodiversity hotspots in the deep ocean, providing hard substrate for attachment in environments otherwise dominated by soft sediments. The complex three-dimensional habitat created by seamount topography supports diverse communities of corals, sponges, and other suspension-feeding organisms that in turn attract fish and other mobile species. Many commercially important fish species aggregate around seamounts, making these features critical for global fisheries while also rendering them vulnerable to overexploitation. The unique environmental conditions of seamounts have also led to high rates of endemism, with numerous species found exclusively on particular seamounts or seamount chains, making these underwater mountains important repositories of marine genetic diversity.

Geologically, seamounts serve as windows into Earth's interior processes, preserving records of volcanic

activity, plate movements, and mantle dynamics that span millions of years. The chemical composition of seamount rocks provides insights into mantle heterogeneity and melting processes, while the age progression of seamount chains offers some of the most compelling evidence for plate tectonic theory. Additionally, seamounts influence sedimentation patterns, trap pelagic sediments, and develop extensive manganese crusts that record long-term changes in ocean chemistry.

## **2.4 Multidisciplinary Research Approach**

The study of seamounts inherently requires a multidisciplinary approach that integrates perspectives from oceanography, geology, biology, chemistry, and even physics. This interdisciplinary nature reflects the complex role seamounts play in Earth systems, bridging the solid Earth, hydrosphere, and biosphere in ways that demand diverse expertise. The historical development of seamount science mirrors this multidisciplinaryity, with early geologists focusing on the volcanic origins of seamounts while oceanographers studied their effects on currents and marine biologists documented their unique biological communities. Notable expeditions such as the HMS Challenger voyage in the 1870s provided the first systematic

## **2.5 Formation and Geological Processes**

Notable expeditions such as the HMS Challenger voyage in the 1870s provided the first systematic scientific documentation of seamounts, though the geological processes that formed these mysterious underwater mountains would remain largely speculative until the plate tectonic revolution of the 1960s transformed our understanding of Earth's dynamics. Today, we recognize that seamounts represent surface expressions of deep Earth processes, primarily volcanic activity shaped by the relentless movement of tectonic plates across our planet's surface. The formation of seamounts encompasses a remarkable diversity of geological mechanisms, each leaving distinct signatures in the rocks and morphology that scientists can decode to reconstruct the complex history of our oceans.

## **2.6 Volcanic Formation Mechanisms**

The primary mechanism for seamount formation involves volcanic activity, though the specific processes vary considerably depending on tectonic setting and underlying mantle conditions. Hotspot volcanism stands as perhaps the most celebrated mechanism, responsible for creating many of the world's most impressive seamount chains. In this process, a relatively stationary plume of exceptionally hot material rises from deep within Earth's mantle, melting as it decompresses near the surface to generate magma that erupts onto the ocean floor. The Hawaiian hotspot provides the quintessential example, having produced the Hawaiian-Emperor seamount chain over approximately 80 million years as the Pacific Plate drifted northwestward above it. This stationary mantle plume has created a remarkable chronological record of volcanic activity, with seamounts becoming progressively older with distance from the currently active Kīlauea volcano on

Hawaii's Big Island. The magma erupted at hotspots typically derives from deep mantle sources with distinct geochemical signatures, allowing scientists to trace the origins and evolution of these volcanic features through chemical analysis of recovered rocks.

Mid-ocean ridges represent another significant setting for seamount formation, though the volcanic processes here differ markedly from hotspot activity. At these spreading centers, where tectonic plates diverge and new oceanic crust forms, magma continually wells up from shallow mantle sources to fill the gap created by plate separation. While most ridge volcanism produces relatively linear features following the spreading axis, off-axis volcanism can create seamounts through various mechanisms. These include volcanic eruptions along transform faults that offset ridge segments, intraplate volcanism triggered by thermal anomalies in the lithosphere near ridges, and the formation of near-ridge seamounts through episodic volcanic events that depart from the main axis of spreading. The Juan de Fuca Ridge in the Pacific Ocean exemplifies this process, having produced numerous seamounts both along its axis and on adjacent flanks through complex interactions between spreading dynamics and localized volcanic activity.

Subduction-related volcanism generates seamounts through entirely different mechanisms, primarily in back-arc basins and through the modification of existing volcanic features. As oceanic plates subduct beneath continental or other oceanic plates, the release of water from hydrated minerals in the descending slab lowers the melting point of overlying mantle wedge material, generating magma that rises to the surface. In back-arc basins—extensional zones behind volcanic arcs—this process can create extensive seamount fields through both fissure eruptions and central vent volcanism. The Mariana back-arc basin in the western Pacific contains thousands of such seamounts, formed in response to the complex interplay between subduction dynamics and back-arc spreading. Additionally, seamounts originally formed on subducting plates may undergo modification through accretion, deformation, or partial melting as they encounter convergent margins, creating hybrid features with complex geological histories.

Intraplate volcanism away from hotspots and plate boundaries represents perhaps the most enigmatic seamount formation mechanism, occurring through processes that continue to generate scientific debate. These intraplate seamounts often form along pre-existing lines of weakness in oceanic crust, such as fracture zones or ancient spreading centers, where stress concentrations facilitate magma ascent despite the absence of obvious thermal anomalies. The New England Seamount Chain in the Atlantic Ocean illustrates this phenomenon, with seamounts arranged along a northeast-southwest trend that appears unrelated to any known hotspot but may instead reflect focused volcanic activity along zones of crustal weakness. Alternative explanations for intraplate seamount formation include small-scale mantle convection, lithospheric cracking due to plate flexure, and the presence of numerous diminutive hotspots too small to create large volcanic islands but sufficient to build seamounts over millions of years.

## 2.7 Plate Tectonic Influences

The movement of tectonic plates provides the organizing framework for understanding seamount distribution and morphology, transforming isolated volcanic features into systematic patterns that record Earth's dynamic history. As oceanic plates migrate across the surface, they encounter various thermal and structural

anomalies that trigger volcanic activity, with the resulting seamounts preserving a spatial record of these encounters. The Hawaiian-Emperor chain offers perhaps the most dramatic illustration of this principle, with its distinctive bend around 47 million years ago recording a major change in the Pacific Plate's motion direction. This age progression, first documented through radiometric dating of seamount samples, provided crucial evidence for plate tectonic theory and demonstrated how seamount chains serve as underwater tape recorders of plate movements. The rate of plate motion over hotspots can be calculated by dividing the distance between seamounts by their age difference, revealing that the Pacific Plate has been moving northwestward at approximately 7-9 centimeters per year over the past 50 million years.

The interaction between seamount-forming processes and spreading centers creates particularly complex geological scenarios. When a hotspot approaches a mid-ocean ridge, the enhanced heat flow and thinner lithosphere near the ridge can dramatically increase volcanic productivity, potentially creating oversized seamounts or even volcanic islands. This process appears to have occurred along the Reykjanes Ridge south of Iceland, where the Iceland hotspot interacts with the Mid-Atlantic Ridge to create elevated topography and enhanced volcanic activity. Conversely, as seamounts formed at hotspots eventually encounter spreading centers, they may be split into halves that migrate in opposite directions, creating paired seamounts on separate plates. The Galápagos Islands and associated seamounts demonstrate this process, with some features having been bisected by the Cocos-Nazca spreading center and now distributed across multiple plates.

Transform faults, which accommodate lateral movement between offset spreading center segments, also influence seamount distribution through various mechanisms. These faults create zones of crustal weakness that can channel magma ascent, leading to linear seamount chains aligned with fault orientations. Additionally, the thermal anomaly along transform faults, generated by frictional heating and enhanced water circulation, may locally lower the lithosphere's strength and facilitate volcanic activity. The Clipperton Transform Fault in the Pacific Ocean, for example, is associated with numerous seamounts that appear to have formed in response to the fault's structural and thermal influence. The complex interplay between transform fault geometry, stress fields, and magma supply creates distinctive patterns of

## **2.8 Global Distribution and Classification**

The complex interplay between transform fault geometry, stress fields, and magma supply creates distinctive patterns of seamount distribution that become even more apparent when viewed from a global perspective. When scientists step back to examine the worldwide distribution of these underwater mountains, remarkable patterns emerge that reflect fundamental Earth processes operating across ocean basins and through geological time. The global geography of seamounts represents not a random scattering of volcanic features but rather a systematic distribution controlled by plate tectonics, mantle dynamics, and the intricate history of our planet's ocean basins. This systematic arrangement allows scientists to read the ocean floor like a historical document, with seamounts serving as the ink that records the story of Earth's geological evolution.



## 2.9 Ocean Basin Distribution

The Pacific Ocean dominates the global seamount inventory in a manner that reflects its unique tectonic history and size. Containing approximately 55,000 seamounts—more than half of the global total—the Pacific basin hosts an underwater mountain landscape unparalleled in scale and diversity. This abundance stems from several factors, including the Pacific's vast area, its complex history of hotspot activity, and the presence of numerous fracture zones and spreading centers that have facilitated volcanic activity over millions of years. The western Pacific, in particular, contains extraordinary concentrations of seamounts, with the region between the Mariana Trench and the Japanese islands featuring thousands of underwater mountains arranged in complex patterns that record the region's dynamic tectonic history. The Pacific's seamounts range in age from recently formed volcanic peaks near active hotspots to ancient, heavily sedimented features dating back over 150 million years, providing a nearly complete record of the basin's volcanic history.

The Atlantic Ocean, while containing fewer seamounts than the Pacific, nevertheless features significant concentrations that reflect its distinct geological evolution. With approximately 8,000 identified seamounts, the Atlantic basin shows a distribution pattern heavily influenced by its mid-ocean ridge system and several hotspot tracks. The seamounts of the Atlantic tend to be younger on average than those in the Pacific, reflecting the basin's more recent origin as Pangaea began to break apart approximately 200 million years ago. Notable Atlantic seamount concentrations include the New England Seamount Chain, which extends southeast from Cape Cod for over 1,000 kilometers, and the numerous seamounts associated with the Bermuda and Azores hotspots. The Atlantic's seamounts also display a distinctive north-south asymmetry, with the northern Atlantic containing more seamounts than the southern portion, a pattern that reflects differences in spreading rates, hotspot distribution, and the complex history of basin opening.

The Indian Ocean's seamount distribution, while less completely mapped than those of the Pacific and Atlantic, reveals patterns shaped by the basin's unique tectonic evolution. Approximately 7,000 seamounts have been identified in the Indian Ocean, with notable concentrations along the Ninetyeast Ridge—an impressive linear feature extending nearly 5,000 kilometers parallel to 90°E longitude. This remarkable seamount chain formed as the Indian Plate moved rapidly northward over the Kerguelen hotspot, creating a chronological record of plate motion that rivals the Hawaiian-Emperor chain in scientific importance. Other significant Indian Ocean seamount provinces include the numerous features associated with the Réunion hotspot near Madagascar and the extensive seamount fields in the Arabian Sea, which reflect the complex interplay between hotspot activity and the unique tectonic setting of the Indian Ocean as it formed during the breakup of Gondwana.

The Southern Ocean and Arctic regions, while containing fewer seamounts than the major ocean basins, host distinctive underwater mountain communities adapted to polar conditions. The Southern Ocean surrounding Antarctica features approximately 3,000 seamounts, many associated with the complex tectonic history of the Antarctic Plate and its interactions with surrounding plates. Notable Southern Ocean seamounts include those along the Pacific-Antarctic Ridge and the numerous features near the Balleny Islands, which record the region's volcanic activity as Antarctica separated from other continents. The Arctic Ocean contains the fewest seamounts of any ocean basin, with only about 300 identified features, reflecting its small size, unique

tectonic history, and the challenges of conducting surveys in ice-covered waters. The Arctic's seamounts, including the impressive Alpha Ridge and the numerous features along the Gakkel Ridge, provide crucial insights into the basin's formation and the complex history of Arctic Ocean opening.

## 2.10 Major Seamount Chains and Provinces

The Hawaiian-Emperor seamount chain stands as perhaps the most spectacular example of a linear seamount province, extending over 5,800 kilometers from the active volcanoes of Hawaii to the Aleutian Trench. This remarkable chain comprises over 80 major seamounts and guyots, recording approximately 80 million years of Pacific Plate movement over the Hawaiian hotspot. The chain's most striking feature is the prominent bend occurring around 47 million years ago, where the chain changes orientation from nearly north-south to northwest-southeast. This bend records a major change in the Pacific Plate's motion direction and provides one of the most compelling pieces of evidence for plate tectonic theory. The Emperor seamounts—the northern segment of the chain—are particularly impressive, with features such as Suiko Seamount rising over 3,000 meters from the seafloor and Detroit Seamount displaying a well-preserved volcanic structure despite its age of approximately 76 million years. The Hawaiian-Emperor chain continues to grow today as the Pacific Plate moves over the stationary Hawaiian hotspot, with Kīlauea volcano on Hawaii's Big Island representing the current active portion of this geological marvel.

The Louisville seamount chain, while less famous than its Hawaiian counterpart, represents an equally impressive linear feature extending across the South Pacific Ocean for over 4,300 kilometers. This chain comprises at least 70 major seamounts formed as the Pacific Plate moved over the Louisville hotspot, which has remained active for approximately 80 million years. Unlike the Hawaiian-Emperor chain, the Louisville chain shows no significant bend in its orientation, suggesting more stable plate motion over the hotspot during its formation. The Louisville seamounts tend to be smaller than their Hawaiian counterparts but display remarkable preservation of volcanic structures, providing scientists with exceptional opportunities to study seamount evolution and the long-term behavior of mantle hotspots. Recent research has revealed that the Louisville hotspot may have originated from the same mantle plume that currently feeds the Hawaiian hotspot, suggesting complex connections between seemingly separate hotspot systems that challenge our understanding of mantle dynamics.

The Walvis Ridge-Rio Grande Rise system represents one of the most intriguing seamount provinces, connecting Africa and South America across the South Atlantic Ocean. This feature formed as the Tristan da Cunha hotspot created volcanic material on both the South American and African plates as they separated during the opening of the South Atlantic. The Walvis Ridge extends southwest from Africa for over 3,000 kilometers, while the Rio Grande Rise extends eastward from South America for approximately 1,500 kilometers, with the two features representing two halves of what was once a continuous volcanic construction. This system provides exceptional evidence for the process of continental breakup, recording how hotspot activity can track the progressive separation of tectonic plates. The Walvis Ridge displays distinctive morphological changes along its length, with older segments featuring more guyots—flat-topped seamounts that once reached sea level—while younger portions retain more pointed volcanic peaks, recording the combined

effects of volcanic construction, erosion, and subsidence through geological time.

The New England Seamount Chain represents one of the most studied Atlantic seamount provinces, extending southeast from Cape Cod for over 1,200 kilometers. Comprising approximately 30 major seamounts and numerous smaller features, this chain formed over approximately 100 million years as the North American Plate moved over what may have been the Great Meteor hotspot. The New England seamounts display a distinctive progression in morphology and age, with younger seamounts in the northwest retaining more pointed volcanic peaks while older seamounts in the southeast have been flattened by wave erosion to form guyots and covered by thick sediment layers. Bear Seamount, the youngest in the chain, rises to approximately 2,000 meters below sea level and supports vibrant biological communities, while the oldest seamounts, such as Nashville Seamount, are heavily sedimented and display the classic flat-topped morphology of ancient guyots. The New England chain has been extensively studied by American scientists due to its relative proximity to the East Coast, providing crucial insights into seamount geology, ecology, and the long-term effects of plate motion over hotspot sources.

## **2.11 Classification Systems**

Scientists have developed various classification systems to organize the immense diversity of seamounts, reflecting different research priorities and the multiple ways these features can be categorized. Size-based classifications represent the most straightforward approach, typically dividing seamounts into categories based on height and volume. Small se

## **2.12 Physical Characteristics and Morphology**

Size-based classifications represent the most straightforward approach, typically dividing seamounts into categories based on height and volume. Small seamounts, generally ranging from 100 to 1,000 meters in height, constitute the majority of the global inventory and often display simple conical shapes with steep slopes. Medium-sized seamounts, rising between 1,000 and 3,000 meters, tend to develop more complex morphologies with multiple volcanic centers and well-defined summit features. Large seamounts, exceeding 3,000 meters in height, frequently evolve into guyots—flat-topped seamounts that once reached sea level as volcanic islands before subsiding to their current depths. This size-based classification reflects not just dimensional differences but also evolutionary stages, as seamounts typically grow larger through successive volcanic eruptions before eventually eroding and subsiding. The relationship between height and base diameter follows predictable patterns, with most seamounts displaying base diameters approximately 3-5 times their height, creating relatively constant flank slopes that typically range between 15 and 25 degrees. However, significant variations occur, with some seamounts displaying exceptionally steep slopes exceeding 45 degrees, particularly those formed by explosive volcanic eruptions or those modified by mass wasting events.

The shape variations among seamounts reveal much about their formation history and subsequent modification processes. Conical seamounts with symmetrical profiles typically indicate formation through steady

volcanic eruptions from a central vent, with minimal subsequent erosion or deformation. Elliptical or elongated seamounts often form along rift zones or through coalescence of multiple volcanic centers, creating complex shapes that record the interplay between volcanic construction and tectonic forces. Some seamounts display distinctive lobate patterns, reflecting the flow of basaltic lava during formation and the subsequent modification by ocean currents and sedimentation. The Mauna Kea seamount, when viewed in its entirety from base to summit, exemplifies the classic shield volcano shape with gentle slopes and a broad base, while smaller seamounts like Davidson Seamount off the California coast display more complex morphologies with multiple summits and irregular profiles that reflect their unique volcanic histories.

### **2.13 Summit Features and Morphology**

The summits of seamounts display remarkable diversity in form and structure, providing crucial clues about their geological evolution and environmental history. Peak shapes range from sharp, pointed volcanic cones that have never reached sea level to broad, flat-topped guyots that preserve records of subaerial erosion. Pointed summits typically characterize younger seamounts formed by effusive basaltic eruptions, where lava steadily accumulates around central vents to build conical structures. The summit of Axial Seamount on the Juan de Fuca Ridge exemplifies this type, featuring a well-defined volcanic cone rising approximately 300 meters above the surrounding seafloor, with a summit caldera that hosts active hydrothermal vents. This caldera, measuring approximately 3 by 8 kilometers, formed through collapse following magma withdrawal, creating a depression that subsequently filled with volcanic material and hydrothermal deposits.

Flat-topped guyots represent perhaps the most distinctive summit morphology, preserving evidence of ancient island environments that have since submerged beneath the waves. These flat surfaces typically form at depths between 1,000 and 2,000 meters, though some occur deeper, recording the combined effects of wave erosion during their emergence as islands and subsequent subsidence as oceanic crust cools and sinks. The guyots of the Hawaiian-Emperor chain, such as Detroit Seamount and Suiko Seamount, display remarkably flat summits that were planed off by wave action when they stood as islands approximately 50-80 million years ago. These flat tops often preserve remnants of beach deposits, coral reefs, and other shallow-water features that provide invaluable insights into ancient sea levels and climate conditions. Some guyots display secondary volcanic features that formed after subsidence, including small cones and lava flows that post-date the flattening process, recording renewed volcanic activity that occurred underwater.

Summit calderas and collapse structures represent common features on many seamounts, particularly those formed through explosive volcanism or those that have experienced significant magma withdrawal. These depressions range from small, circular pits a few hundred meters across to massive collapse structures several kilometers in diameter. The caldera at Vailulu'u Seamount in the Samoan chain, discovered in 1975, measures approximately 2 kilometers in diameter and reaches depths of 800 meters below the surrounding summit, providing a spectacular example of summit collapse. Such calderas often host hydrothermal systems that support unique biological communities, making them particularly important sites for scientific research. Secondary volcanic features, including parasitic cones, lava domes, and fissure eruptions, frequently modify summit morphology, creating complex topography that can host diverse habitats for marine organisms.

## 2.14 Flank Structures and Characteristics

The flanks of seamounts display a rich variety of structural features that record the complex interplay between volcanic construction, tectonic modification, and erosional processes. Terracing and bench formation represent common flank characteristics, often developing at specific depths where changes in eruption style or sediment accumulation rates create distinctive step-like features. These terraces can form through various mechanisms, including changes in lava composition that affect flow characteristics, variations in eruption rates that create constructional platforms, or differential erosion that removes softer materials while preserving more resistant layers. The flanks of many seamounts in the Pacific display prominent terraces at depths of approximately 500-800 meters, possibly reflecting changes in sea level that affected eruption styles during glacial-interglacial cycles.

Landslide scars and deposits provide dramatic evidence of mass wasting processes that continually modify seamount morphology. These features range from small, localized slump scars a few hundred meters across to massive collapse structures that remove entire flank sectors. The Hawaiian Islands and associated seamounts display some of the most spectacular landslide deposits on Earth, with individual events having displaced volumes exceeding 5,000 cubic kilometers of material. These submarine landslides create distinctive hummocky topography on the seafloor and can generate tsunamis when they occur rapidly. The flank of Davidson Seamount contains numerous landslide scars that record ongoing slope instability, with some deposits extending tens of kilometers from the seamount base. These mass wasting events play crucial roles in seamount evolution by removing oversteepened slopes, redistributing volcanic material, and creating new habitats for colonization by marine organisms.

Rift zones and volcanic ridges represent important flank structures on many seamounts, particularly those formed through prolonged volcanic activity. These linear features typically develop along zones of structural weakness where magma preferentially ascends, creating ridges that extend away from the summit. The rift zones of Hawaiian volcanoes extend both underwater and above sea level, with submarine portions displaying well-developed volcanic ridges that record the direction of lava flow and structural control on eruption location. These features can extend for many kilometers from the seamount summit, creating complex radial patterns that reflect the interplay between volcanic construction and pre-existing structures in the oceanic crust. Erosional gullies and channels further modify seamount flanks, particularly in areas where

## 2.15 Ecosystems and Biodiversity

Erosional gullies and channels further modify seamount flanks, particularly in areas where strong currents interact with complex topography, creating dynamic underwater landscapes that profoundly influence the distribution and diversity of life. The physical complexity of seamounts, with their varied slopes, terraces, and structural features, provides an ideal foundation for the development of some of the most remarkable ecosystems in the deep ocean. These underwater mountains function as biodiversity hotspots in otherwise relatively barren abyssal plains, creating three-dimensional habitats that support communities of extraordinary richness and uniqueness. The interaction between seamount morphology and oceanographic processes

generates environmental conditions that foster enhanced productivity, support specialized biological communities, and promote the evolution of species found nowhere else on Earth.

## **2.16 Primary Productivity and Food Webs**

The enhanced primary productivity around seamounts represents one of the most significant ecological consequences of their interaction with ocean currents. As water masses encounter seamounts, the acceleration of flow around their flanks and the generation of turbulence create conditions that bring nutrient-rich deep waters toward the surface through a process known as current-induced upwelling. This vertical transport of nutrients, including nitrate, phosphate, and silicate, fuels phytoplankton growth in the euphotic zone above seamounts, creating localized areas of elevated productivity in otherwise oligotrophic ocean regions. The enhanced productivity extends through the water column, with seamounts effectively functioning as underwater oases that concentrate biological activity in their vicinity. The formation of Taylor columns—rotating water masses that become trapped above seamount summits—further enhances productivity by retaining phytoplankton and zooplankton in the vicinity of the seamount, creating a self-sustaining ecosystem that supports higher trophic levels.

The pelagic-benthic coupling around seamounts represents a crucial mechanism for energy transfer from surface waters to deep-sea communities. Enhanced productivity in surface waters leads to increased export of organic matter through sinking particles, which provide food resources for benthic organisms on seamount flanks and summits. This vertical flux of organic material is particularly important in the deep ocean, where food resources are typically scarce and patchily distributed. Seamounts effectively concentrate these falling particles, creating enriched feeding grounds for suspension-feeding organisms that would otherwise struggle to obtain sufficient nutrition. The food web structure around seamounts typically begins with phytoplankton and bacteria, extends through zooplankton and small pelagic fish, and culminates in diverse benthic communities and commercially important fish species. This trophic structure creates complex interdependencies that make seamount ecosystems particularly vulnerable to disturbances at any level of the food web.

## **2.17 Benthic Communities**

The benthic communities of seamounts represent some of the most diverse and structurally complex ecosystems in the deep ocean, dominated by organisms that require hard substrate for attachment in environments otherwise characterized by soft sediments. Cold-water corals form the foundation of many seamount communities, creating three-dimensional habitats that support numerous other species. These corals, including species such as *Primnoa resedaeformis*, *Paragorgia arborea*, and various *Lophelia* species, can form extensive forests and gardens that cover seamount summits and flanks. The coral gardens of Davidson Seamount off the California coast exemplify this phenomenon, with dense aggregations of large gorgonian corals creating habitat complexity comparable to terrestrial forests. These coral communities can live for centuries to millennia, providing long-term stable habitat that allows for the development of highly specialized communities with complex ecological relationships.



Sponge communities represent another crucial component of seamount benthic ecosystems, with glass sponges and other demosponges forming dense aggregations that filter water and provide habitat for numerous other organisms. The hexactinellid sponges of seamounts in the North Pacific, including species such as *Farea occa* and *Euplectella aspergillum*, create spectacular skeletal structures that can reach several meters in height. These sponges host diverse microbial communities that may participate in nutrient cycling and chemical processes important to ecosystem function. Crustacean assemblages on seamounts include numerous species of crabs, shrimp, and lobsters, many of which have evolved specialized relationships with coral and sponge habitats. The seamounts off New Zealand support commercially important populations of species such as the scarlet prawn (*Haliporoides sibogae*) and various crab species that have adapted to the unique environmental conditions of these underwater mountains.

Microbial mats and chemosynthetic communities represent perhaps the most cryptic but ecologically significant components of seamount benthic ecosystems. In areas where hydrothermal activity occurs, chemosynthetic bacteria form the base of food webs that are independent of sunlight-derived productivity. The Lost City hydrothermal field on Atlantis Massif supports extensive microbial communities that derive energy from chemical reactions between seawater and ultramafic rocks, creating ecosystems that may resemble conditions on other planetary bodies. Even seamounts without active hydrothermal vents support diverse microbial communities that play crucial roles in nutrient cycling, organic matter decomposition, and the transformation of chemical compounds that affect water quality and ecosystem function.

## 2.18 Fish Communities and Aggregations

Fish communities around seamounts display remarkable diversity and abundance, making these features critical for both marine biodiversity and commercial fisheries. Demersal fish assemblages typically include species adapted to hard substrate environments and strong current conditions, with many species displaying morphological and behavioral adaptations for life on seamounts. The orange roughy (*Hoplostethus atlanticus*), once heavily targeted by commercial fisheries, forms large aggregations around seamounts during spawning periods, gathering in densities that can exceed thousands of individuals per hectare. These aggregations typically occur at specific depths and times of year, reflecting reproductive cycles that have evolved to take advantage of seamount environments. Other commercially important demersal species include various alfonsoins (*Beryx* spp), oreos (*Alloctytus* spp), and cardinalfishes (*Epigonus* spp), many of which have life history characteristics that make them particularly vulnerable to overexploitation.

Pelagic fish associations with seamounts represent another important ecological phenomenon, with numerous species of tunas, billfishes, and sharks using seamounts as feeding grounds, navigation references, and staging areas for migrations. The seamounts of the Azores and Madeira regions in the Atlantic Ocean support important populations of blue sharks (*Prionace glauca*), shortfin mako sharks (*Isurus oxyrinchus*), and various tuna species that aggregate to feed on the enhanced productivity and prey concentrations around these features. These pelagic associations create important linkages between seamount ecosystems and broader oceanic food webs, facilitating energy transfer across different depth zones and habitat types. The seasonal movements of pelagic species around seamounts often follow predictable patterns that reflect changes in

water temperature, prey availability, and reproductive cycles.

Spawning aggregation sites represent perhaps the most critical ecological function of seamounts for many fish species, with numerous species gathering at specific seamounts during predictable periods to reproduce. These aggregations can involve thousands to millions of individuals and represent crucial events in the life cycles of many species. The seamounts off southern Japan support spawning aggregations of Japanese anchovy (*Engraulis japonicus*) and other pelagic species that have supported fisheries for centuries. Similarly, seamounts in the Mediterranean Sea host spawning aggregations of commercially important species such as European hake (*Merluccius merluccius*) and red mullet (*Mullus surmuletus*). The predictable nature of these spawning aggregations makes the fish particularly vulnerable to fishing pressure, as fishers can target large concentrations of reproductively active individuals during critical periods in their life cycles.

### **2.19 Biogeography and Endemism**

Seamounts exhibit remarkably high rates of endemism, with numerous species found exclusively on particular seamounts or seamount chains, making these underwater mountains important repositories of marine genetic diversity. Estimates suggest that up to 30-40% of species on

### **2.20 Oceanographic Influence and Climate Connections**

individual seamounts may be endemic, reflecting the isolation and unique environmental conditions that characterize these underwater mountains. This remarkable species endemism extends beyond the biological realm to influence the very physics and chemistry of the oceans surrounding these features, creating a complex interplay between life and oceanographic processes that shapes the marine environment on both local and global scales.

### **2.21 Oceanographic Influence and Climate Connections**

The influence of seamounts on oceanographic processes extends far beyond their immediate vicinity, creating ripple effects that propagate through ocean basins and contribute to the regulation of Earth's climate system. As massive obstacles to ocean flow, seamounts fundamentally alter the movement of water masses, generate complex turbulence patterns, and facilitate the mixing of waters from different depths and regions. These physical modifications create distinctive oceanographic environments that not only support the unique biological communities previously discussed but also play crucial roles in broader ocean circulation patterns and climate regulation. The interaction between seamounts and ocean currents represents one of the most significant ways these underwater features influence planetary-scale processes, transforming them from mere geological formations into active agents of oceanographic and climate dynamics.

Current interactions with seamounts produce some of the most dramatic oceanographic phenomena in the deep ocean, fundamentally altering the behavior of water masses as they encounter these massive underwater obstacles. When ocean currents flow past seamounts, the acceleration of water around the flanks creates



zones of enhanced velocity that can reach speeds several times greater than the ambient flow. This acceleration effect, well-documented around seamounts such as the Cobb Seamount in the North Pacific, generates complex flow patterns that include eddies, recirculation zones, and wakes that can extend for many kilometers downstream of the feature. The formation of these wake eddies represents a crucial mechanism for energy dissipation in ocean currents, with the kinetic energy of large-scale flows being converted into smaller-scale turbulent motions that enhance mixing and vertical exchange. The Hawaiian Islands provide perhaps the most spectacular example of this phenomenon, with the island chain creating a wake of alternating vortices that extends for hundreds of kilometers to the west, significantly altering regional circulation patterns and creating predictable zones of upwelling and convergence that influence marine productivity and weather patterns.

Internal wave dynamics around seamounts represent another crucial oceanographic influence, with these underwater mountains acting as major generators of internal waves that propagate through the ocean's stratified layers. As tidal currents and other oscillatory flows encounter seamount topography, they generate internal waves that can travel horizontally for hundreds of kilometers and vertically through the water column. These waves, which occur at the interface between water layers of different densities, play essential roles in ocean mixing and the transport of heat, nutrients, and other properties. The breaking of internal waves on seamount flanks creates intense turbulence that can enhance vertical mixing rates by factors of 10-100 compared to background ocean conditions. This mixing process is particularly important in bringing nutrient-rich deep waters toward the surface, supporting the enhanced productivity that characterizes many seamount ecosystems. Measurements around the Fieberling Seamount in the Pacific Ocean have documented internal wave breaking events that generate turbulence sufficient to completely overturn the water column in localized areas, creating mixing hotspots that influence regional ocean chemistry and biology.

Water mass modification around seamounts occurs through several mechanisms that create distinctive oceanographic signatures and influence broader circulation patterns. The formation of Taylor columns—rotating water masses that become trapped above seamount summits—represents perhaps the most fascinating of these phenomena. When water flows over a seamount in a rotating system, the Coriolis effect can cause the water column to spin up and become trapped above the feature, creating a relatively isolated body of water that can persist for weeks to months. These trapped water masses develop distinctive properties that differ from surrounding waters, often showing enhanced biological productivity and modified temperature and salinity characteristics. The Taylor column above Cobb Seamount has been extensively studied and shown to support a distinct biological community that differs from that of surrounding waters at similar depths. Similarly, the seamounts of the Emperor Chain in the North Pacific create multiple Taylor columns that influence regional circulation patterns and facilitate the retention of larvae and other biological materials, contributing to the high endemism rates previously discussed.

The climate system connections of seamounts operate through multiple pathways that influence global heat transport, carbon cycling, and climate regulation. By enhancing vertical mixing and upwelling, seamounts contribute to the exchange of heat between the ocean's surface and interior, affecting the distribution of thermal energy that drives atmospheric circulation patterns. The enhanced productivity around seamounts also influences carbon cycling through the biological pump, where phytoplankton growth draws down at-

mospheric carbon dioxide that subsequently sinks to the deep ocean as organic matter. This process represents a crucial mechanism for carbon sequestration that helps regulate Earth's climate over geological timescales. Recent research has suggested that the collective effect of the world's seamounts on ocean circulation and mixing may be significant enough to influence global climate patterns, particularly in regions where seamounts are abundant such as the Pacific Ocean. The interactions between seamounts and climate systems operate both ways, with climate change potentially altering seamount ecosystems through changes in ocean temperature, chemistry, and circulation patterns.

Acoustic and seismic effects represent another important oceanographic influence of seamounts, with these massive underwater features significantly affecting the propagation of sound and seismic waves through ocean waters. The hard rock surfaces and steep topography of seamounts efficiently scatter acoustic energy, creating complex sound fields that both challenge and enable various oceanographic applications. This acoustic scattering makes seamounts detectable using sonar systems but also creates acoustic shadows and interference patterns that complicate underwater communication and navigation. The acoustic properties of seamounts have important implications for marine life, as many species rely on sound for communication, navigation, and prey detection. The distinctive acoustic environments around seamounts may influence the behavior and distribution of vocalizing species such as whales and dolphins. Similarly, the interaction of seismic waves with seamount topography affects the propagation of earthquake energy through ocean basins, with seamounts acting as both barriers and waveguides that modify seismic wave patterns. These acoustic and seismic effects have practical applications in seamount detection, geological mapping, and even in the search for underwater military installations, demonstrating the far-reaching oceanographic influence of these remarkable underwater mountains.

The cumulative oceanographic effects of seamounts on global ocean systems represent an active area of research that continues to reveal new insights into how these underwater mountains influence planetary-scale processes. As scientists develop more sophisticated measurement techniques and numerical models, the complex interactions between seamounts and ocean dynamics become increasingly clear, highlighting the crucial role these features play in maintaining ocean health and regulating Earth's climate system. This understanding becomes particularly important as human activities increasingly impact ocean environments, making the preservation of seamount ecosystems not just a matter of conservation but a necessity for maintaining the oceanographic processes that support life on Earth.

## **2.22 Human Discovery and Exploration History**

The profound oceanographic and climate influences of seamounts that we have just explored would remain largely unknown to humanity for most of our history, hidden beneath miles of water beyond the reach of human observation. Yet these underwater mountains have played a crucial role in human maritime activities for centuries, first as mysterious navigational hazards and later as subjects of intense scientific investigation. The story of human discovery and exploration of seamounts represents a remarkable journey from superstition and speculation to systematic scientific understanding, driven by technological innovation and insatiable curiosity about the hidden landscapes of our planet. This historical narrative not only chronicles

our expanding knowledge of seamounts but also reflects the broader evolution of marine science and our relationship with the oceans themselves.

### 2.23 Early Navigation and Discovery

The earliest human encounters with seamounts occurred through the indirect experience of mariners who navigated the world's oceans long before the existence of modern navigation aids. For centuries, sailors documented mysterious areas where soundings would suddenly reveal shallow depths in otherwise deep ocean regions, phenomena often attributed to supernatural causes or simple navigational errors. These early encounters were particularly common in well-traveled shipping lanes where seamounts created hazards for vessels relying on lead line soundings for navigation. The waters around the Azores and Madeira islands in the Atlantic Ocean, for instance, were notorious among Portuguese and Spanish sailors for unexpected shoals that seemed to appear and disappear with changing weather conditions, leading to legends of phantom islands and malevolent sea spirits. These mariners' observations, however fragmentary and superstitious, represent the first human documentation of seamounts, though their true nature would remain misunderstood for centuries.

The systematic scientific investigation of seamounts began in earnest during the 19th century, as oceanography emerged as a distinct scientific discipline and nations sponsored ambitious expeditions to explore the world's oceans. The HMS Challenger expedition, conducted between 1872 and 1876, stands as perhaps the most significant early scientific voyage in the discovery and documentation of seamounts. This groundbreaking British expedition, equipped with specially designed sounding gear and sampling equipment, systematically mapped ocean depths across the globe and collected specimens from previously unexplored regions. During its three-year journey, the Challenger's scientists documented numerous seamounts, including several in the Pacific Ocean that would later prove to be part of major seamount chains. The expedition's chief scientist, Sir Charles Wyville Thomson, marveled at the discovery of underwater mountains rising thousands of feet from the ocean floor, noting in his journals how these features challenged contemporary understanding of ocean basin formation. The Challenger's pioneering work laid the foundation for modern seamount science, establishing methodologies for deep-sea exploration and creating the first comprehensive catalog of underwater topographic features.

Other 19th-century expeditions expanded upon the Challenger's discoveries, with national pride driving multiple countries to sponsor oceanographic voyages that contributed to the growing knowledge of seamounts. The German research vessel *Meteor* conducted extensive surveys in the South Atlantic between 1925 and 1927, discovering numerous seamounts including the impressive Walvis Ridge, which extends southwest from Africa for over 3,000 kilometers. These early expeditions faced enormous technological challenges, using primitive sounding gear that required ships to remain stationary for hours to obtain reliable depth measurements. Despite these limitations, the cumulative data from these voyages began to reveal patterns in seamount distribution that would later prove crucial for understanding plate tectonics and hotspot theory. The meticulous charts and observations created by these early oceanographers, though crude by modern standards, represent invaluable historical records that continue to inform scientific research today.

## 2.24 Technological Evolution in Seamount Detection

The lead line sounding era that dominated early seamount detection gave way gradually to more sophisticated technologies as the 20th century progressed, transforming our ability to map and understand underwater topography. The development of echo sounding in the early 1900s revolutionized seamount detection by allowing ships to measure depths continuously while underway, dramatically increasing the efficiency and accuracy of seafloor mapping. The German expedition *Meteor* was among the first to employ this new technology systematically, using echo sounders to create detailed depth profiles across the South Atlantic. Echo sounding worked by transmitting sound pulses through the water column and measuring the time required for these signals to travel to the seafloor and return, a simple yet powerful principle that enabled the discovery of thousands of previously unknown seamounts. The improved resolution of echo sounding compared to lead line methods revealed the true shapes of seamounts for the first time, showing that many were not simple conical features but complex structures with multiple peaks, calderas, and other morphological details.

World War II accelerated the development of seamount detection technologies dramatically, as naval powers sought more effective methods for submarine detection and navigation. The intense research effort devoted to sonar (sound navigation and ranging) during this conflict produced technological breakthroughs that would later be applied to peaceful scientific exploration. American naval vessels, while conducting anti-submarine patrols in the Pacific Ocean, routinely documented seamounts that posed hazards to navigation or provided potential hiding places for enemy submarines. These wartime observations, collected by thousands of vessels across the world's oceans, created an unprecedented database of seamount locations that would prove invaluable to postwar scientific research. The transition of military sonar technology to civilian applications after the war equipped oceanographic institutions with powerful new tools for seamount detection, leading to a rapid expansion in the known inventory of underwater mountains.

The satellite altimetry revolution that began in the 1970s represented perhaps the most transformative development in seamount detection, allowing scientists to map seamounts remotely from space. This remarkable technology works by measuring subtle variations in sea surface height that reflect the gravitational influence of underwater topography. Seamounts, being massive structures of dense rock, create slight bulges in the sea surface above them as their gravitational attraction pulls ocean water upward. These bulges, typically only a few centimeters high but extending for dozens of kilometers, can be detected by satellite radar altimeters with extraordinary precision. The SEASAT mission, launched by NASA in 1978, provided the first comprehensive satellite-based view of seafloor topography, revealing thousands of previously unknown seamounts. Subsequent satellite missions, including GEOSAT, TOPEX/Poseidon, and the Jason series, have progressively improved the resolution and accuracy of satellite altimetry, creating a nearly complete global map of seamount distribution. This technological leap transformed seamount science from a discipline limited by the slow pace of ship-based surveys to one capable of systematic global mapping, revealing that seamounts are far more abundant than previously imagined.

## 2.25 Golden Age of Seamount Exploration

The period from the 1950s through the 1970s witnessed what many scientists consider the golden age of seamount exploration, characterized by ambitious international expeditions and groundbreaking discoveries that transformed our understanding of these underwater mountains. This era saw the emergence of seamount science as a distinct field of study, with dedicated research programs focused specifically on understanding the geology, biology, and oceanography of seamounts. The Scripps Institution of Oceanography launched numerous expeditions during this period, including the Capricorn Expedition in 1952-1953 which systematically surveyed seamounts in the South Pacific and provided crucial evidence for the hotspot theory of seamount formation. These expeditions benefited from postwar technological advances and increased funding for scientific research, enabling comprehensive investigations that combined geological mapping, biological sampling, and oceanographic measurements.

International collaboration became a hallmark of golden age seamount exploration, with scientists from multiple countries pooling resources and expertise to tackle the complex questions surrounding seamount formation and ecology. The International Indian Ocean Expedition, conducted from 1959 to 1965, involved over 40 research vessels from 13 countries and produced the first systematic survey of seamounts in this previously understudied ocean basin. Similarly, the International Decade of Ocean Exploration in the 1970s sponsored numerous seamount research projects that brought together scientists from around the world to study these underwater mountains. These collaborative efforts not only accelerated scientific progress but also established the international networks and methodologies that continue to support seamount research today. The golden age was characterized by a sense of excitement and discovery, as each expedition seemed to reveal new seamount chains, unexpected biological communities, or geological features that challenged existing theories.

Deep submergence vehicles played a crucial role in advancing seamount science during this period, allowing scientists for the first time to observe seamounts directly rather than relying solely on remote sensing and sampling. The bathyscaphe Trieste, which descended to the bottom of the Challenger Deep in 1960, also conducted numerous dives to seamount summits, providing the first visual documentation of se

## 2.26 Economic Resources and Exploitation

The golden age of seamount exploration that revealed the scientific wonders of these underwater mountains inevitably gave way to a new era focused on their economic potential. As scientists documented the rich biological communities, valuable mineral deposits, and unique geological features of seamounts, commercial interests quickly recognized the economic opportunities hidden beneath the waves. This transition from pure scientific inquiry to economic exploitation represents a natural progression in human interaction with marine resources, reflecting our species' enduring tendency to seek value in newly discovered environments. The economic exploitation of seamounts has developed into a complex global enterprise encompassing fisheries, mining, biotechnology, energy extraction, and even tourism, each presenting unique opportunities and challenges for sustainable management of these remarkable underwater resources.

Fisheries and commercial exploitation represent the most developed and economically significant form of seamount utilization, with commercial fishing operations targeting seamount communities for over half a century. The discovery that seamounts support dense aggregations of commercially valuable fish species sparked a fishing boom that began in earnest during the 1960s and continues to this day, albeit with increasing regulation and conservation concerns. The orange roughy (*Hoplostethus atlanticus*) stands as perhaps the most infamous example of seamount fisheries exploitation, with this deep-water fish forming massive spawning aggregations around seamounts that were quickly targeted by commercial fleets. New Zealand fishermen discovered orange roughy aggregations on seamounts off their coast in the late 1970s, sparking an international fishing frenzy that saw global catches peak at approximately 90,000 tons annually in the early 1990s. The fish's bright orange color, mild flavor, and high market value made it extremely popular, particularly in American and European markets, where it was often marketed as “deep sea perch” or “sea perch” to make it more appealing to consumers. Unfortunately, the biological characteristics that made orange roughy aggregations so attractive to fishers—their tendency to gather in predictable locations during spawning, their slow growth rates, and their exceptional longevity (individuals can live for over 150 years)—also made them extremely vulnerable to overexploitation. Many seamount orange roughy populations collapsed within years of intensive fishing, with some stocks declining by over 90% and showing little sign of recovery even decades later.

Other commercially important species have been similarly exploited on seamounts worldwide, including various alfonosins (*Beryx* spp), oreos (*Allocyttus* spp), cardinalfishes (*Epigonus* spp), and pelagic armorheads (*Pseudopentaceros richardsoni*). The seamounts off southern Japan and the Korean Peninsula support valuable fisheries for alfonosins and various deep-water snappers, while the seamounts of the South Atlantic have been heavily fished for oreos and related species. The fishing methods employed on seamounts have evolved over time, with early operations using simple bottom longlines and gillnets before the development of more sophisticated and destructive techniques. Bottom trawling, which involves dragging heavy nets across the seafloor, became the dominant method for seamount fishing by the 1980s due to its efficiency in catching dense aggregations of demersal fish. However, this fishing method causes severe damage to seamount ecosystems, destroying ancient coral gardens and sponge communities that may have taken centuries or millennia to develop. The economic value of seamount fisheries, while substantial in many regions, often masks the true cost of exploitation when ecosystem services, biodiversity loss, and long-term sustainability are considered.

Mineral resources on seamounts represent another potentially valuable economic resource that has attracted increasing commercial interest in recent decades. The most significant of these resources are ferromanganese crusts, which form slowly on seamount surfaces through the precipitation of manganese and iron oxides from seawater. These crusts, which can grow to thicknesses of over 20 centimeters over millions of years, are enriched in valuable metals including cobalt, nickel, copper, and rare earth elements that are crucial for modern technology. The cobalt-rich ferromanganese crusts of seamounts in the Pacific Ocean, particularly those within the Exclusive Economic Zones of Pacific island nations, contain some of the highest concentrations of cobalt found in marine deposits, with some crusts containing up to 2% cobalt by weight. This has led to considerable interest from mining companies and nations seeking to secure supplies of these



strategic metals, particularly as demand for cobalt has increased due to its use in batteries for electric vehicles and electronic devices. The economic potential of these crusts is substantial, with some estimates suggesting that a single large seamount could contain ferromanganese crusts worth hundreds of millions of dollars at current market prices.

Phosphorite deposits represent another valuable mineral resource found on some seamounts, particularly those that were once emergent islands or that experienced strong upwelling of nutrient-rich waters. These phosphate-rich rocks form through the accumulation and cementation of phosphatic skeletal material from marine organisms, creating deposits that can be mined for fertilizer production. The seamounts off California and Baja California, for instance, contain significant phosphorite deposits that were mined during the mid-20th century when phosphate prices were high. Hydrothermal mineralization on seamounts creates yet another type of mineral resource, with active and inactive hydrothermal vents depositing valuable metals including copper, zinc, gold, and silver. The Lost City hydrothermal field on Atlantis Massif, for example, hosts extensive deposits of calcium carbonate and other minerals that have attracted scientific and commercial interest. The economic exploitation of seamount mineral resources remains largely in the exploratory phase due to technical challenges, environmental concerns, and regulatory uncertainties, but the potential value of these resources continues to drive investment in deep-sea mining technologies.

Bioprospecting and biotechnology represent an emerging economic frontier for seamounts, as scientists discover that the unique organisms living in these environments produce biochemical compounds with remarkable properties and potential applications. The extreme conditions on many seamounts—high pressure, low temperatures, limited light, and unique chemical environments—have led to the evolution of organisms with specialized metabolic pathways and unusual biochemical adaptations. These adaptations have resulted in the production of novel compounds that show promise for pharmaceutical development, industrial applications, and biotechnology. Cold-water corals from seamounts, for instance, produce compounds with anti-inflammatory and anti-cancer properties that are being investigated by pharmaceutical companies. Similarly, sponges from seamount communities have yielded molecules with antimicrobial, antiviral, and antitumor activities, some of which are currently in various stages of drug development. The microorganisms associated with seamount hydrothermal vents represent another promising source of biotechnological applications, with their enzymes (extremozymes) capable of functioning under extreme conditions that would denature typical enzymes, making them valuable for industrial processes that require high temperatures, pressures, or chemical extremes.

The economic potential of seamount bioprospecting has led to the development of specialized research programs and commercial ventures focused on discovering and developing marine natural products. However, this nascent industry faces significant challenges related to access to genetic resources, benefit-sharing with nations that control seamount territories, and the development of sustainable collection methods that don't damage fragile seamount ecosystems. The Nagoya Protocol on Access and Benefit-Sharing, which came into effect in 2014, has created an international framework for regulating bioprospecting activities and ensuring that the economic benefits derived from genetic resources are shared fairly with the countries that provide them. This regulatory framework has helped to balance the economic potential of bioprospecting with conservation concerns

## 2.27 Scientific Research Methods and Technologies

This regulatory framework has helped to balance the economic potential of bioprospecting with conservation concerns, but effective management of seamount resources ultimately depends on our ability to understand these complex underwater environments through advanced scientific research. The study of seamounts presents extraordinary technical challenges due to their remote locations, extreme depths, and the vast scales involved, requiring sophisticated methodologies and cutting-edge technologies that continue to evolve at a remarkable pace. From the early days of lead-line soundings to modern autonomous systems, seamount science has consistently been at the forefront of oceanographic innovation, driving technological development that benefits not only seamount research but marine science as a whole.

Mapping and survey techniques have undergone revolutionary advances since the first crude depth measurements of seamounts, transforming our ability to visualize underwater topography with unprecedented detail and accuracy. Multibeam echosounder systems represent the cornerstone of modern seamount mapping, using sophisticated acoustic arrays to simultaneously measure depths across wide swaths of seafloor rather than the single-point measurements characteristic of earlier echo sounders. These systems, typically mounted on research vessel hulls or towed in deep-tow configurations, can map seamounts with resolutions as fine as one meter while covering areas hundreds of meters wide with each pass of the vessel. The multibeam system on the research vessel *Falkor*, operated by the Schmidt Ocean Institute, has produced spectacular high-resolution maps of previously uncharted seamounts in the South Pacific, revealing volcanic cones, lava flows, and sediment patterns invisible to earlier generations of scientists. Side-scan sonar complements multibeam mapping by providing detailed acoustic imagery of seafloor texture and morphology, allowing researchers to distinguish between different rock types, identify landslide deposits, and locate biological communities such as coral gardens that create distinctive acoustic signatures. Seismic reflection methods add another dimension to seamount surveys by penetrating beneath the seafloor to reveal internal structure, showing layers of volcanic material, sediment sequences, and even the underlying crustal structure that controls seamount formation. Gravity and magnetic surveys complete the mapping toolkit by measuring variations in Earth's gravitational and magnetic fields that reflect the density and magnetic properties of seamount rocks, helping to distinguish between different volcanic rock types and infer the deep structure of seamounts.

Sampling and collection methods provide the ground truth that validates remote sensing measurements and allows scientists to directly study the rocks, sediments, and organisms that compose seamount ecosystems. Rock dredging, one of the oldest sampling techniques, remains valuable for collecting volcanic rock samples from seamount flanks and summits, despite its relatively crude nature. Modern dredges have been refined with improved chain designs, better mesh sizes, and location tracking systems that increase their effectiveness and allow researchers to precisely map where samples were collected. Sediment sampling techniques range from simple gravity corers that drive tubes into soft sediment to sophisticated piston corers capable of extracting sediment sequences dozens of meters long, preserving records of seamount environmental history that can span millions of years. The JOIDES Resolution scientific drilling vessel has recovered sediment cores from seamounts that contain detailed records of ocean chemistry, climate change, and biological evolu-



tion extending back over 100 million years. Biological collection methods have evolved from simple trawls and nets to sophisticated remotely operated tools that can selectively collect specimens without damaging fragile organisms. The submersible Alvin, operated by Woods Hole Oceanographic Institution, has been instrumental in collecting delicate deep-sea corals and sponges from seamounts using specialized manipulator arms and collection chambers that maintain organisms at deep-sea conditions during ascent to the surface. In-situ measurement instruments represent perhaps the most innovative sampling approach, allowing scientists to study seamount environments without removing samples from their natural context. These instruments include chemical sensors that measure water composition, current meters that document flow patterns around seamounts, and biological observatories that can document organism behavior and ecosystem processes over extended periods.

Remote sensing applications have dramatically expanded our ability to study seamounts at regional to global scales, complementing ship-based measurements with comprehensive spatial coverage. Satellite altimetry, previously discussed in the context of seamount discovery, continues to improve in resolution and accuracy, with modern missions such as Sentinel-3 and Jason-3 capable of detecting seamounts as small as one kilometer in height through their subtle gravitational influence on sea surface height. This technology has enabled the creation of nearly complete global inventories of seamounts, revealing that these features are far more abundant than previously estimated, with recent studies suggesting over 100,000 seamounts rise more than 100 meters from the seafloor. Satellite oceanography provides complementary information on the biological productivity around seamounts through measurements of ocean color, sea surface temperature, and chlorophyll concentration, allowing scientists to identify productive seamounts and study how they influence regional oceanography. However, optical remote sensing has inherent limitations for seamount studies, as light cannot penetrate beyond the upper few meters of ocean water, leaving the deep environments where most seamounts occur accessible only through acoustic and other non-optical methods. Future satellite missions promise to overcome some of these limitations, with planned missions such as the Surface Water and Ocean Topography (SWOT) satellite expected to provide unprecedented resolution of sea surface height variations that will improve seamount detection and characterization.

Underwater vehicle technologies have revolutionized seamount research by providing direct access to these remote environments while dramatically expanding the spatial and temporal scope of investigations. Remotely operated vehicles (ROVs) such as the Jason/Medea system operated by Woods Hole Oceanographic Institution have become workhorses of seamount research, combining advanced maneuverability with sophisticated sampling capabilities and high-definition video systems that allow scientists to observe seamount ecosystems in real time from research vessels. These systems can operate at depths exceeding 6,000 meters while carrying specialized equipment including rock samplers, biological collection tools, and an array of sensors for measuring environmental conditions. Autonomous underwater vehicles (AUVs) represent the cutting edge of seamount exploration technology, with vehicles such as Sentry and REMUS capable of conducting detailed surveys without direct human control, following programmed missions that can last for days while mapping seamounts with centimeter-scale precision. These vehicles have discovered previously unknown seamounts and documented unexpected geological features such as active hydrothermal vents on seamounts previously thought to be geologically extinct. Human-occupied vehicles continue to play crucial

roles in seamount research despite the rise of robotic systems, with submersibles such as Alvin and Shinkai 6500 providing unique capabilities for direct observation, rapid decision-making, and complex sampling operations that remain difficult to automate. Hybrid vehicle systems that combine the advantages of ROVs and AUVs are increasingly being deployed for seamount research, with tethered autonomous vehicles offering the freedom of movement characteristic of AUVs while maintaining the real-time communication and power delivery advantages of ROVs.

Data analysis and modeling approaches transform the vast amounts of information collected through these diverse methodologies into scientific understanding and predictive capability. Geographic information systems (GIS) provide the foundation for modern seamount research by allowing scientists to integrate multiple types of data—bathymetry, geology, biology, chemistry, and oceanography—into comprehensive spatial databases that reveal patterns and relationships impossible to discern from individual datasets. Numerical modeling of seamount processes has become increasingly sophisticated, with computational fluid dynamics models capable of simulating how currents interact with seamount topography, predicting the formation of Taylor columns and internal waves that influence seamount ecosystems. These models have been instrumental in understanding how seamounts enhance vertical mixing and productivity, helping to explain the ecological significance of these underwater mountains. Statistical analysis methods ranging from simple correlation analyses to complex multivariate techniques allow researchers to identify patterns in seamount biodiversity, understand the factors that control species distributions, and assess the impacts of human activities on seamount ecosystems. Machine learning applications represent the newest frontier in seamount data analysis, with artificial intelligence algorithms being used to classify seamount morphology from sonar data, predict species distributions based on environmental variables, and even identify previously unknown seamounts in satellite altimetry data. These advanced analytical approaches,

## **2.28 Environmental Threats and Conservation**

These advanced analytical approaches, while enhancing our scientific understanding of seamounts, have simultaneously revealed the extent and severity of environmental threats facing these remarkable underwater ecosystems. As our capacity to study seamounts has expanded, so too has our awareness of how human activities are impacting these fragile environments, creating an urgent need for comprehensive conservation strategies and remediation efforts. The intersection of expanded scientific knowledge and escalating anthropogenic impacts has transformed seamount science from a purely academic pursuit into a discipline with crucial implications for marine conservation and sustainable resource management.

## **2.29 Fishing Impacts and Overexploitation**

Bottom trawling represents arguably the most destructive human impact on seamount ecosystems, with fishing gear causing extensive damage to habitats that may require centuries or even millennia to recover. This fishing method, which involves dragging heavy nets equipped with steel bobbins and rockhopper gear across the seafloor, effectively bulldozes everything in its path, destroying ancient coral gardens, sponge commu-

nities, and the complex three-dimensional habitat structure that supports diverse marine life. The seamounts off southern Australia provide a particularly stark example of this destruction, where commercial trawling for orange roughy and oreos has removed up to 99% of coral cover from heavily fished seamounts, leaving behind barren rock surfaces that show little sign of recovery even after decades of protection. Scientific surveys of these impacted seamounts reveal ghostly landscapes where massive coral colonies, some estimated to be over 4,000 years old, have been reduced to rubble fields, eliminating critical habitat for numerous fish and invertebrate species that depend on these structural foundations for survival.

The biological impacts of seamount fishing extend far beyond habitat destruction to include direct overexploitation of fish populations that display life history characteristics making them particularly vulnerable to fishing pressure. Many seamount fish species grow slowly, mature late, and live exceptionally long lives—adaptations that evolved in the relatively stable deep-sea environment but become liabilities when faced with intensive fishing pressure. The orange roughy fisheries collapse represents perhaps the most notorious example of this vulnerability, with populations on numerous seamounts in the North Atlantic and South Pacific declining by over 90% within years of intensive fishing commencing. The seamounts around New Zealand and Australia witnessed particularly devastating declines, with some orange roughy populations falling to less than 5% of their original biomass and showing minimal recovery even decades after fishing reductions. Similar patterns have occurred with other seamount fisheries, including the armorhead fishery on the Emperor Seamounts, which collapsed in the 1980s after only a few years of intensive exploitation, and various oreo fisheries that have experienced boom-and-bust cycles around seamounts in the South Atlantic and Indian Oceans.

Bycatch and ecosystem effects compound the direct impacts of seamount fishing, creating cascading consequences that extend through entire marine food webs. Bottom trawls targeting demersal fish species inevitably capture numerous non-target species, including deep-water sharks, rays, and invertebrates that play crucial ecological roles but have little or no commercial value. The seamount fisheries of the North Atlantic have particularly high bycatch rates, with studies showing that up to 50% of catch weight in some trawls consists of non-target species that are typically discarded dead or dying. These bycatch species often include slow-growing sharks and rays that are even more vulnerable to population declines than the target fish species, creating additional pressure on already stressed seamount ecosystems. The removal of key predatory and prey species through both targeted fishing and bycatch fundamentally alters seamount food webs, creating trophic cascades that can cause unexpected population explosions of some species and declines of others, ultimately reducing ecosystem resilience and stability.

### **2.30 Mining and Extraction Threats**

The emerging threat of deep-sea mining for seamount mineral resources represents a potentially transformative impact that could rival or even exceed fishing in its environmental consequences. Ferromanganese crusts, which form slowly on seamount surfaces over millions of years and contain valuable cobalt, nickel, copper, and rare earth elements, have attracted increasing interest from mining companies and nations seeking to secure supplies of these critical metals. The International Seabed Authority has already issued numer-

ous exploration contracts for seamount crust mining, with companies from China, Japan, Korea, and various European nations conducting surveys to assess the commercial viability of extracting these resources. The proposed mining methods involve scraping crusts from seamount surfaces using massive machines that would remove not only the valuable mineral deposits but also the biological communities living on and within these crusts. Environmental impact assessments suggest that such mining operations could eliminate up to 90% of biological diversity on mined seamounts, with recovery potentially requiring millions of years due to the extremely slow growth rates of both ferromanganese crusts and the organisms that inhabit them.

Historical mining attempts provide sobering lessons about the potential impacts of modern seamount mining operations. The phosphate mining conducted on seamounts off California and Baja California during the mid-20th century created extensive disturbance that remains visible decades after mining ceased. These operations removed not only the phosphate deposits but also overlying biological communities, creating large barren areas that have shown only limited natural recovery. The extensive sediment plumes generated by mining operations smothered adjacent areas, extending damage beyond the immediate mining zones and affecting biological communities over distances of several kilometers. Modern mining technologies would operate at much greater depths and affect vastly larger areas than these historical operations, potentially creating environmental impacts that could affect entire seamount chains and the ocean basins in which they occur. The difficulty of monitoring and enforcing environmental regulations in the deep ocean further compounds these concerns, creating potentially irreparable damage to some of the most pristine and poorly understood ecosystems on Earth.

### **2.31 Pollution and Contamination**

Marine debris accumulation on seamounts represents an insidious threat that has only recently been recognized by scientists, with underwater surveys revealing that these underwater mountains function as collection points for plastic pollution and other marine debris. Ocean currents that accelerate around seamounts create eddies and convergence zones that trap floating debris, causing accumulation rates that can exceed those in surrounding ocean waters by orders of magnitude. Research on seamounts in the North Pacific has documented concentrations of microplastics in sediments that are among the highest recorded in the deep ocean, with these particles being ingested by filter-feeding organisms and entering deep-sea food webs. The slow degradation rates of plastics in cold, deep-water environments mean that this pollution persists essentially indefinitely, creating a long-term contamination problem that will continue to affect seamount ecosystems for centuries or millennia. Ghost fishing gear lost during commercial fishing operations represents another particularly damaging form of marine debris, with lost nets and traps continuing to catch and kill marine life long after being abandoned, creating ongoing mortality that can significantly impact local populations.

Chemical contamination from various sources, including industrial discharge, agricultural runoff, and atmospheric deposition, accumulates in seamount food webs through biomagnification processes that can reach toxic levels in top predators. The long lifespans and slow metabolic rates of many seamount organisms make them particularly vulnerable to bioaccumulation of persistent organic pollutants and heavy metals. Studies on seamount fish species have documented concentrations of mercury and other contaminants that

exceed safe consumption levels for humans, reflecting the efficiency with which these deep-sea ecosystems accumulate chemical

## 2.32 Notable Seamounts and Case Studies

pollutants over time. The slow degradation rates of plastics in cold, deep-water environments mean that this pollution persists essentially indefinitely, creating a long-term contamination problem that will continue to affect seamount ecosystems for centuries or millennia. To fully appreciate the ecological significance and conservation needs of these remarkable underwater mountains, it is instructive to examine specific seamounts that have become particularly important in scientific research, conservation efforts, and our broader understanding of marine ecosystems. These case studies illustrate both the extraordinary value of seamounts and the diverse challenges they face in an increasingly human-impacted ocean.

Davidson Seamount stands as perhaps the most celebrated success story in seamount conservation, demonstrating how scientific research and public engagement can lead to effective protection of these vulnerable ecosystems. Located approximately 120 kilometers southwest of Monterey, California, this underwater mountain rises 2,280 meters from the seafloor to within 1,250 meters of the ocean surface, creating an extensive area of hard substrate in a region otherwise dominated by soft sediments. Discovered in 1933 by the U.S. Coast and Geodetic Survey vessel Davidson, the seamount remained largely unstudied until 2000, when scientists from the Monterey Bay Aquarium Research Institute conducted the first comprehensive exploration using the remotely operated vehicle Tiburon. What they discovered was extraordinary: a vibrant garden of deep-sea corals and sponges covering the seamount's summit and flanks, with some coral colonies estimated to be over 1,000 years old. These ancient corals, including species such as *Paragorgia arborea* and *Primnoa resedaeformis*, create complex three-dimensional habitat that supports diverse communities of fish and invertebrates. The documentation of this remarkable ecosystem, combined with striking high-definition video footage, sparked public interest and political will for protection. In 2008, Davidson Seamount became the first seamount to be designated as a marine protected area under the U.S. National Marine Sanctuaries Program, specifically the Monterey Bay National Marine Sanctuary. This protection prohibits bottom trawling and other destructive fishing practices while allowing limited scientific research. Ongoing monitoring programs have documented the effectiveness of this protection, with coral communities showing signs of recovery in areas previously impacted by fishing gear. The Davidson Seamount story has become a model for seamount conservation worldwide, demonstrating how scientific discovery, effective communication, and thoughtful policy can work together to protect these vulnerable deep-sea ecosystems.

The Emperor Seamounts represent the longest continuous seamount chain on Earth, extending over 5,800 kilometers from near the Aleutian Trench to the Hawaiian Islands and recording approximately 80 million years of Pacific Plate movement over the Hawaiian hotspot. This remarkable chain comprises over 80 major seamounts and guyots, each representing a snapshot of volcanic activity frozen in time as the Pacific Plate drifted northwestward. The most striking feature of the Emperor chain is its distinctive bend around 47 million years ago, where the chain changes orientation from nearly north-south to northwest-southeast. This bend records a major change in the Pacific Plate's motion direction and provides one of the most compelling

pieces of evidence for plate tectonic theory. Scientific drilling of several Emperor seamounts, including Detroit Seamount and Suiko Seamount, has provided invaluable samples of volcanic rock that allow precise dating of formation events and detailed analysis of magma composition over time. These studies have revealed that the Hawaiian hotspot has remained remarkably stable in its chemical composition over 80 million years, suggesting a deep mantle source that has resisted mixing with surrounding mantle material. The Emperor seamounts display a fascinating progression in morphology as they age, with younger seamounts retaining pointed volcanic peaks while older features have been flattened by wave erosion to form classic guyots with flat tops that preserve records of ancient sea levels and climate conditions. The Emperor chain also supports important fisheries, particularly for armorhead fish in the 1960s and 1970s, though these fisheries collapsed after just a few years of intensive exploitation, providing an early warning about the vulnerability of seamount ecosystems to overfishing. Today, the Emperor Seamounts continue to serve as a natural laboratory for understanding plate tectonics, hotspot dynamics, and the long-term evolution of volcanic islands, making them perhaps the most scientifically valuable seamount chain on Earth.

Saya de Malha Bank, located in the Indian Ocean between the Seychelles and Mauritius, represents the largest submerged bank in the world's oceans, covering an area of approximately 40,000 square kilometers with depths ranging from 7 to 65 meters below sea level. Unlike typical seamounts that rise sharply from abyssal depths, Saya de Malha Bank is a massive gently-sloping plateau that never reaches the surface, creating a unique shallow-water environment in the middle of the Indian Ocean. The bank formed through a complex combination of volcanic activity and coral reef growth, with volcanic foundations created by the Réunion hotspot subsequently covered by extensive coral reef development during periods of lower sea level. Today, the bank supports exceptionally productive ecosystems, with extensive seagrass beds, coral communities, and algal habitats that provide crucial feeding grounds for migratory species including green sea turtles and numerous fish species. The shallow waters and high productivity make Saya de Malha Bank an important spawning and nursery area for commercially valuable fish species, particularly tuna, which aggregate in large numbers to feed on the abundant prey. The bank's remote location and relatively shallow depths make it particularly vulnerable to climate change, with ocean warming and acidification threatening the coral communities that form the foundation of its ecosystems. Despite its ecological importance, Saya de Malha Bank remains poorly studied due to its remote location and the challenges of conducting research in this vast area. Recent satellite studies have revealed that the bank significantly influences regional ocean circulation, creating distinctive patterns of water movement that affect weather patterns and biological productivity throughout the western Indian Ocean. The potential economic value of Saya de Malha Bank's fisheries has led to increased interest from surrounding nations, creating governance challenges as the bank lies beyond the exclusive economic zones of any country, highlighting the need for international cooperation in managing these shared marine resources.

Vema Seamount, located in the South Atlantic Ocean approximately 1,600 kilometers west of Cape Town, South Africa, represents one of the most intensively studied seamounts in the world's oceans and serves as a cautionary tale about the impacts of seamount exploitation. Discovered in 1959 by the research vessel Vema, this isolated seamount rises 4,600 meters from the seafloor to within 26 meters of the ocean surface, making it one of the shallowest known seamounts. Its accessibility and location in productive waters made Vema



Seamount an immediate target for commercial fishing, with Soviet and Japanese fleets beginning intensive operations in the 1960s targeting the abundant populations of armorhead fish (*Pseudopentaceros richardsoni*). These fish formed dense aggregations around the seamount during spawning, creating a fishery that peaked at approximately 40,000 tons annually in the late 1960s before collapsing catastrophically to less than 5% of original biomass within just a few years. Scientific studies conducted during this period documented the rapid decline of fish populations and associated changes in the seamount ecosystem, providing some of the first comprehensive data on the impacts of seamount fishing. The biological communities of Vema Seamount were also unusual, supporting populations of species typically found in much colder waters

### 2.33 Future Perspectives and Research Directions

As we reflect on the remarkable diversity of seamounts exemplified by these case studies, from the protected coral gardens of Davidson Seamount to the geological grandeur of the Emperor chain, we find ourselves standing at a pivotal moment in human understanding and stewardship of these underwater mountains. The coming decades promise transformative advances in seamount science and management, driven by technological innovation, growing recognition of ecosystem services, and increasing urgency to address environmental challenges. Yet this progress will occur against a backdrop of escalating human impacts and climate change, creating both unprecedented opportunities and daunting challenges for the scientists, policymakers, and conservationists working to understand and protect these remarkable features of our planet's ocean floor.

Emerging research frontiers in seamount science are expanding rapidly as new technologies and methodologies enable investigations that were impossible just a decade ago. Climate change impacts on seamounts represent perhaps the most urgent research priority, as scientists race to understand how warming oceans, acidification, and deoxygenation will affect these vulnerable ecosystems. Recent research on seamounts off the coast of Tasmania has documented concerning changes in coral communities, with some species showing signs of stress and reduced growth rates in response to warming waters. Similarly, studies on seamounts in the Mediterranean Sea have revealed that increasing ocean acidity is affecting the ability of calcifying organisms like corals and mollusks to build their skeletons, potentially undermining the foundation of these ecosystems. The future of deep-sea mining represents another critical research frontier, as scientists work to develop more accurate environmental impact assessments and explore alternative mining technologies that might reduce ecosystem damage. The International Seabed Authority's recent regulations requiring baseline environmental surveys before mining operations commence have created both opportunities and challenges for seamount researchers, who must develop standardized methodologies for documenting seamount biodiversity and ecosystem function across diverse ocean basins. Genetic connectivity studies using advanced DNA sequencing techniques are revolutionizing our understanding of how seamount populations maintain connections across vast ocean distances, with recent work on seamount-dwelling fish revealing unexpectedly high levels of gene flow that challenge conventional wisdom about seamount isolation. Finally, microbial ecosystem investigations are uncovering the hidden majority of seamount biodiversity, with metagenomic studies revealing extraordinary diversity in bacterial and archaeal communities that play crucial roles in nutrient cycling and ecosystem function.

Technological developments on the horizon promise to dramatically enhance our ability to study and monitor seamounts with unprecedented detail and coverage. Advanced autonomous systems represent the cutting edge of seamount exploration, with new generations of artificial intelligence-powered underwater vehicles capable of making independent decisions about sampling locations and data collection priorities. The Schmidt Ocean Institute's recently launched vehicle AUV SuBastian has already demonstrated remarkable capabilities in mapping seamounts with centimeter-scale precision while simultaneously collecting environmental DNA samples that document biodiversity without physical collection of organisms. Real-time monitoring capabilities are expanding through the development of sophisticated sensor networks and satellite communication systems that can transmit data from seamount observatories directly to laboratories worldwide. The Ocean Networks Canada system, which includes seamount monitoring stations off the British Columbia coast, provides a glimpse of this future, with live video feeds and continuous environmental measurements enabling scientists to observe seamount ecosystems in real time rather than relying on periodic ship-based surveys. Enhanced mapping technologies are pushing the boundaries of seamount visualization, with synthetic aperture sonar systems creating photographic-quality images of seafloor topography that reveal details as small as individual coral branches and rock formations. These advances are complemented by new data processing algorithms that can automatically classify seamount habitats and identify features of interest, dramatically reducing the time required to process the massive datasets generated by modern seamount surveys. Perhaps most excitingly, deep-sea observatory networks are being developed that will create persistent monitoring capabilities on seamounts worldwide, with planned installations including the proposed Pacific Seamount Observatory Array that would monitor dozens of seamounts across the Pacific basin for decades, providing unprecedented insights into long-term ecosystem changes and climate impacts.

Policy and governance challenges for seamounts are becoming increasingly complex as human activities expand into deeper waters and more remote ocean regions. The management of international waters presents particularly daunting challenges, as most seamounts lie beyond national jurisdiction in areas where governance mechanisms remain fragmented and often inadequate. The United Nations Convention on the Law of the Sea provides the basic framework for high seas governance, but implementation mechanisms for seamount protection remain weak, with few binding requirements for conservation or sustainable use. Deep-sea mining regulations have emerged as one of the most contentious policy issues surrounding seamounts, with the International Seabed Authority struggling to balance economic development with environmental protection as it develops the Mining Code that will govern future extraction of seamount mineral resources. The recent adoption of the High Seas Treaty represents a potentially transformative development for seamount governance, creating a framework for establishing marine protected areas in international waters and requiring environmental impact assessments for activities that might affect seamount ecosystems. Fisheries management improvements are urgently needed as well, with many seamount fisheries still operating without adequate scientific understanding or precautionary management measures. The Western and Central Pacific Fisheries Commission's recent adoption of closures for vulnerable seamount ecosystems provides a promising model, but similar measures are needed in other ocean regions where seamount fishing continues largely unregulated. Climate change mitigation represents the ultimate policy challenge for seamount conservation, as even the most effective local management measures may be overwhelmed by



global changes in ocean temperature, chemistry, and circulation patterns that affect seamounts regardless of their protection status.

Knowledge gaps and research priorities in seamount science remain substantial despite decades of investigation, reflecting the enormous technical challenges and vast scales involved in studying these underwater mountains. Biodiversity estimation challenges persist as one of the most fundamental knowledge gaps, with current estimates of seamount species diversity varying by orders of magnitude and many seamount regions remaining completely unsampled. Recent expeditions to previously unexplored seamounts in the Clarion-Clipperton Zone have consistently discovered dozens of new species, suggesting that our current understanding of seamount biodiversity represents only a fraction of the true total. Connectivity understanding needs represent another critical research priority, as scientists still have limited knowledge of how seamount populations exchange larvae and genetic material across ocean basins. This gap has important implications for conservation, as connected seamount networks may require different management approaches than isolated seamounts. Ecosystem service valuation is increasingly recognized as essential for justifying seamount conservation investments, but comprehensive assessments of the economic and cultural values provided by seamounts remain rare. The few studies that have been conducted suggest that seamounts provide services worth billions of dollars annually through fisheries, climate regulation, and potential bioprospecting discoveries, but these values are rarely incorporated into management decisions. Long-term monitoring requirements represent perhaps the most challenging knowledge gap to address, as understanding how seamount ecosystems change over time requires sustained observation programs that extend beyond typical research funding cycles. The establishment of seamount observatory networks and the development of automated monitoring technologies offer promising approaches to addressing this gap, but significant investment and international coordination will be needed to implement comprehensive monitoring programs at the scale required.

Seamounts in the Earth system context represent an emerging frontier in scientific understanding, as researchers increasingly recognize that these underwater mountains play crucial roles in global biogeochemical cycles, ocean circulation, and climate regulation. The role of seamounts in global biogeochemical cycles extends far beyond their local environments, with enhanced mixing and productivity around seamounts affecting nutrient distribution and carbon cycling throughout ocean basins. Recent modeling studies suggest that the collective effect of the world's seamounts on ocean mixing may be sufficient to influence global patterns of heat distribution and carbon storage, potentially affecting climate regulation at planetary scales. The importance of seamounts for ocean health is becoming increasingly apparent as scientists document how these features serve as biodiversity reservoirs, productivity hotspots, and refuges for species affected by climate change and other stressors. Climate regulation functions of seamounts operate through multiple pathways, including their influence on ocean circulation patterns, their role in carbon sequestration through enhanced biological productivity, and their potential to serve as natural laboratories for understanding climate impacts on marine ecosystems. Future research integration needs will require bringing together perspectives from geology, biology, oceanography, climate science, and social sciences to develop comprehensive understanding of how seamounts function within the Earth system and how they might respond to ongoing global changes. This integrated approach will