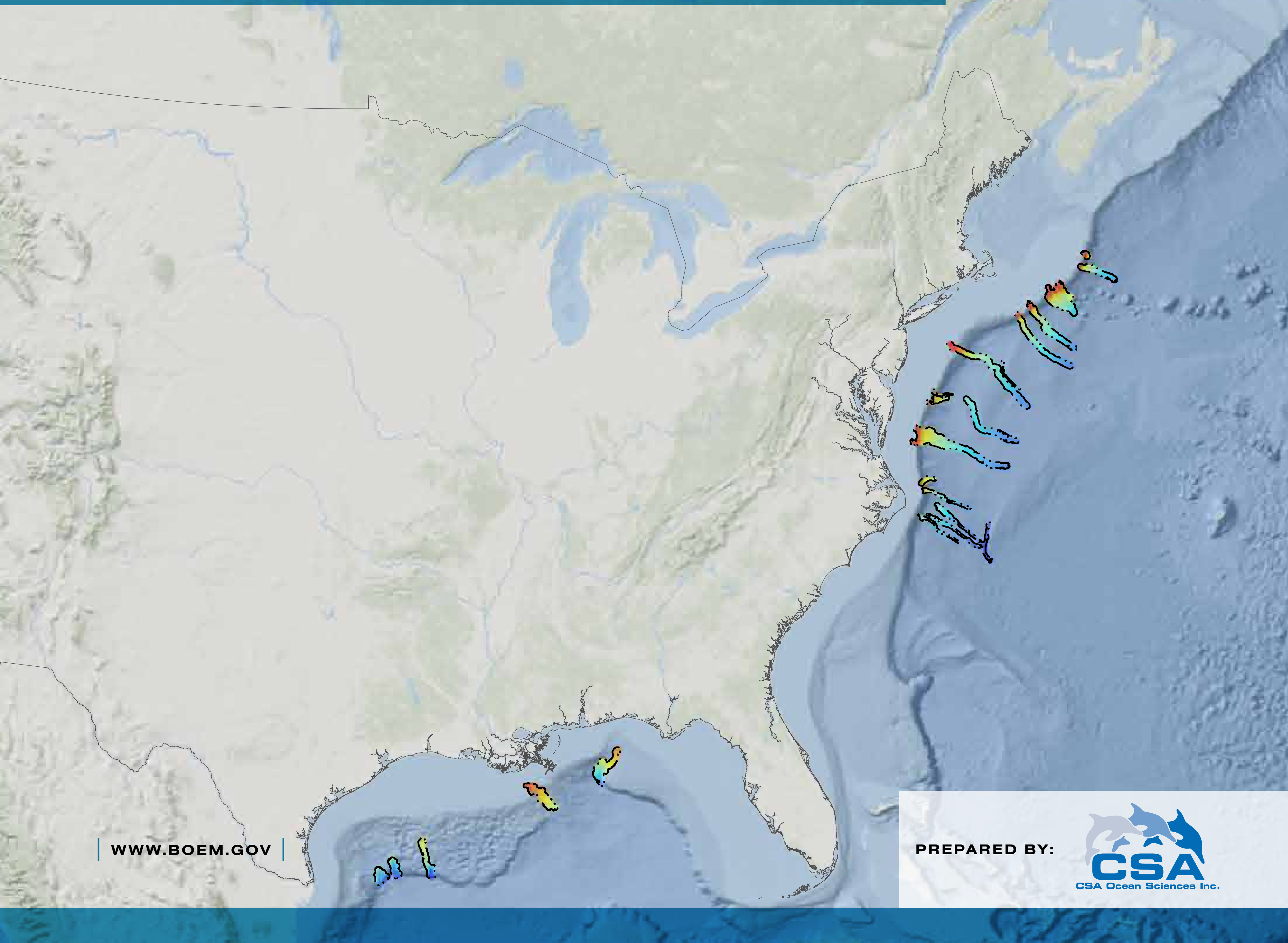
OCS Study
BOEM 2019-066

BOEM Bureau of Ocean Energy Management

LARGE SUBMARINE CANYONS OF THE UNITED STATES OUTER CONTINENTAL SHELF ATLAS



WWW.BOEM.GOV

PREPARED BY: CSA Ocean Sciences Inc.

ABOUT THIS ATLAS

The purpose of this Atlas is to facilitate improved environmental management of the Outer Continental Shelf (OCS) by developing one depository of maps and information on major submarine canyons of the OCS. This Atlas provides the Bureau of Ocean Energy Management (BOEM) with geospatial and resource information to assist in the preparation of environmental documents. To accomplish this, submarine canyons were inventoried and delineated using a methodology consistent with terrestrial watershed mapping. A criteria-based algorithm generated spatial polygons used to calculate canyon slope, length, and depth. A concurrent literature review was conducted, which provided the notable facts seen in the Atlas. In addition, the literature citations were cataloged in an EndNote library and a synopsis there of was embedded in the geodatabase files.

Canyon polygons developed by Harris et al. (2014) (hereinafter, Harris) was the starting point for defining canyon boundaries and guiding the initial canyon inventory and selection process. Harris utilized both geographic information system (GIS) tools (Topographic Position Index, calculated by comparing each cell slope value to the mean slope of the cell's neighbors) and the judgement of subject matter experts (SMEs). For this project, CSA Ocean Sciences Inc. (CSA) developed an objective, numerically repeatable delineation process using the Harris data as a starting point. As with Harris, canyon bathymetry, and subsequently, their boundaries were derived using Shuttle Radar Topography Mission (SRTM30) data because of its consistent geographic coverage.

The first step in this process was to extract the approximate Harris canyon thalweg, which represents the deepest continuous path down the canyon. The bathymetric data were clipped at the Harris polygon border for thalweg extraction using the Strahler method in the Esri Toolbox (Strahler 1957). The Strahler method assigns stream order values to tributaries as they intersect one another. Typically, the first three stream orders were adequate to create a continuous polyline through the Harris canyon extent; in less linear and more dendritic canyon systems, a fourth largest stream order was utilized to ensure an continuous polyline. To simplify the stream order network, $\log_{10}$ was applied to the result of the flow accumulation tool before calculating stream order.

Around each canyon thalweg, bathymetric data from a series of boundary extents were evaluated to determine the effect of spatial extent on computing potential canyon boundaries. CSA examined five boundary extents (1, 3, 5, 10, and 20 km) by buffering around the thalweg to define a preliminary canyon boundary. For each of those boundary extents, data extraction was performed by applying a slope analysis tool to compute slopes.

Sequential elimination of flatter slopes from the boundary extents progressively decreased the boundary extent toward the canyon thalweg. The Harris boundary for some canyons was most closely approximated by the 50th percentile of the data within the boundary extent, making the Harris boundary a very conservative boundary extent estimate (i.e., contained mostly the steepest slopes). From this evaluation, it was decided that slope data smaller (flatter) than the 4.6th percentile (i.e., 2 standard deviations [2SDs]) should be eliminated to ensure inclusion of larger (steeper) canyon features and because data outside of 2SDs are traditionally considered to be outliers to a distribution.

The effect of boundary extent on the 2SD percentile was also examined for three visually distinct canyon geometry scenarios. The three geometry scenarios were: 1) isolated and narrow relative to length, 2) isolated and wide relative to length, and 3) canyon systems (many canyons occurring conterminously). For each of these canyon scenarios, the 2SD percentile was plotted as a function of the five boundary extents and visually examined for sensitivity of the 2SD percentile to these extent by canyon geometry scenario combinations. By evaluating how seafloor slope percentiles stabilized as a function of boundary extents, it was concluded that use of the 2SD percentile within a 10-km boundary would be used to eliminate surrounding seafloor from the definition of canyon boundaries.

Harris PT, Macmillan-Lawler M, Rupp J, Baker EK. 2014. Geomorphology of the oceans. Mar Geol. 352:4-24.

Strahler AN. 1957. Quantitative analysis of watershed geomorphology. Eos, Trans Amer Geophys Union. 38(6):913-20.

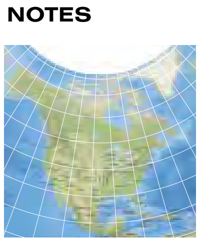
LARGE SUBMARINE CANYONS OF THE UNITED STATES OUTER CONTINENTAL SHELF ATLAS

Table Of Contents

DISCLAIMER

Study concept, oversight, and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Contract Number 140M0119F0009. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

NOTES



This study includes both the continental US and Alaska. Different projections were used to account for differences in location relative to the North pole to present a less visually distorted map view. However, this results in a trade-off because one or the other (map view or associated coordinates) will be distorted due to the convergence of parallels and meridians with proximity to the geographic north pole. More specifically, a map projection uses mathematical formulas to relate spherical coordinates on the globe to flat, planar coordinates. In all projected coordinate systems, intervals of latitude and longitude decrease as they get closer to the poles. Although the coordinate system selected here for Alaska, has a less visually distorted map view, its graticules (the network of lines representing meridians and parallels on which a map is represented) and associated coordinates necessarily appear distorted on the map and do not align at perfect 90-degree angles due to the projection of the map relative to the curvature of the earth and proximity to the poles.

The oblique 3D views were included to show the canyons and perceive the difference in height between the canyon floor and rim. The oblique 3D views shown here are vertically exaggerated, are not to scale, and do not necessarily show the complete length of each canyon. The views were oriented to optimize 3D visualization and from a position and angle that displays the most dynamic relief within each canyon.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2019-066. The report is also available at the National Technical Reports Library at https://ntrl.ntis.gov/NTRL/.

CITATION

CSA Ocean Sciences Inc., De Leo FC, Ross SW. 2019. Large submarine canyons of the United States outer continental shelf atlas. Sterling (VA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2019-066. 51 p.

Collaborators

CSA Ocean Sciences Inc.

MELANIE L. CAHILL, Project Manager
STEPHEN T. VIADA, Technical Lead
MARK S. FONSECA, Technical Advisor
STEVE W. ROSS, Technical Expert
FABIO C. DE LEO, Technical Expert
DUSTIN MYERS, Cartographer
BRIAN DIUNIZIO, Cartographer
BRENT GORE, Cartographer
CHARLES HAGENS, Cartographer
EMILLE RODRIGUEZ, Graphic Designer
KRISTEN L. METZGER, Librarian
ASHLEY A. LAWSON, Project Scientist

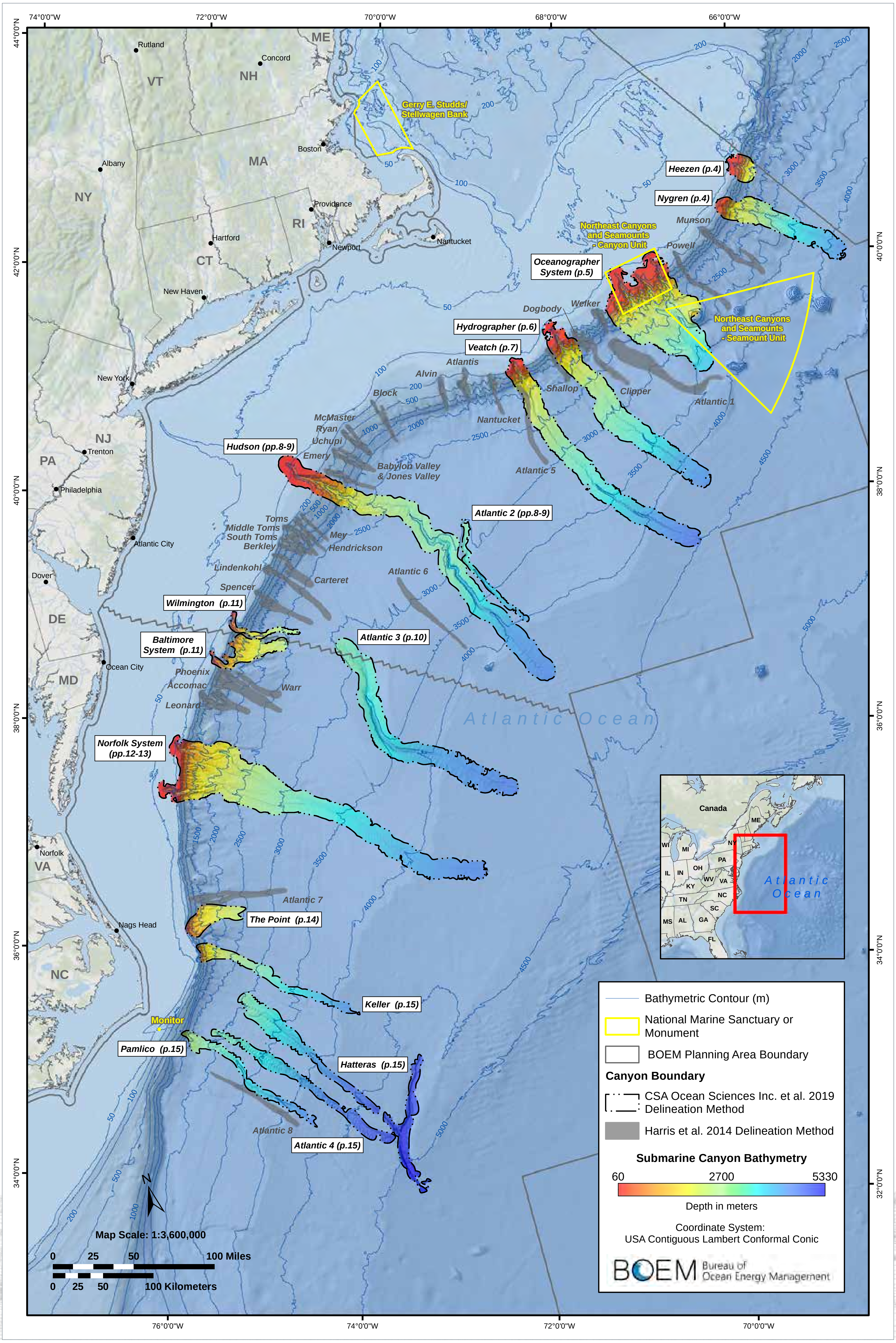
esri

KEITH VANGRAAFEILAND, Living Atlas Ocean Lead

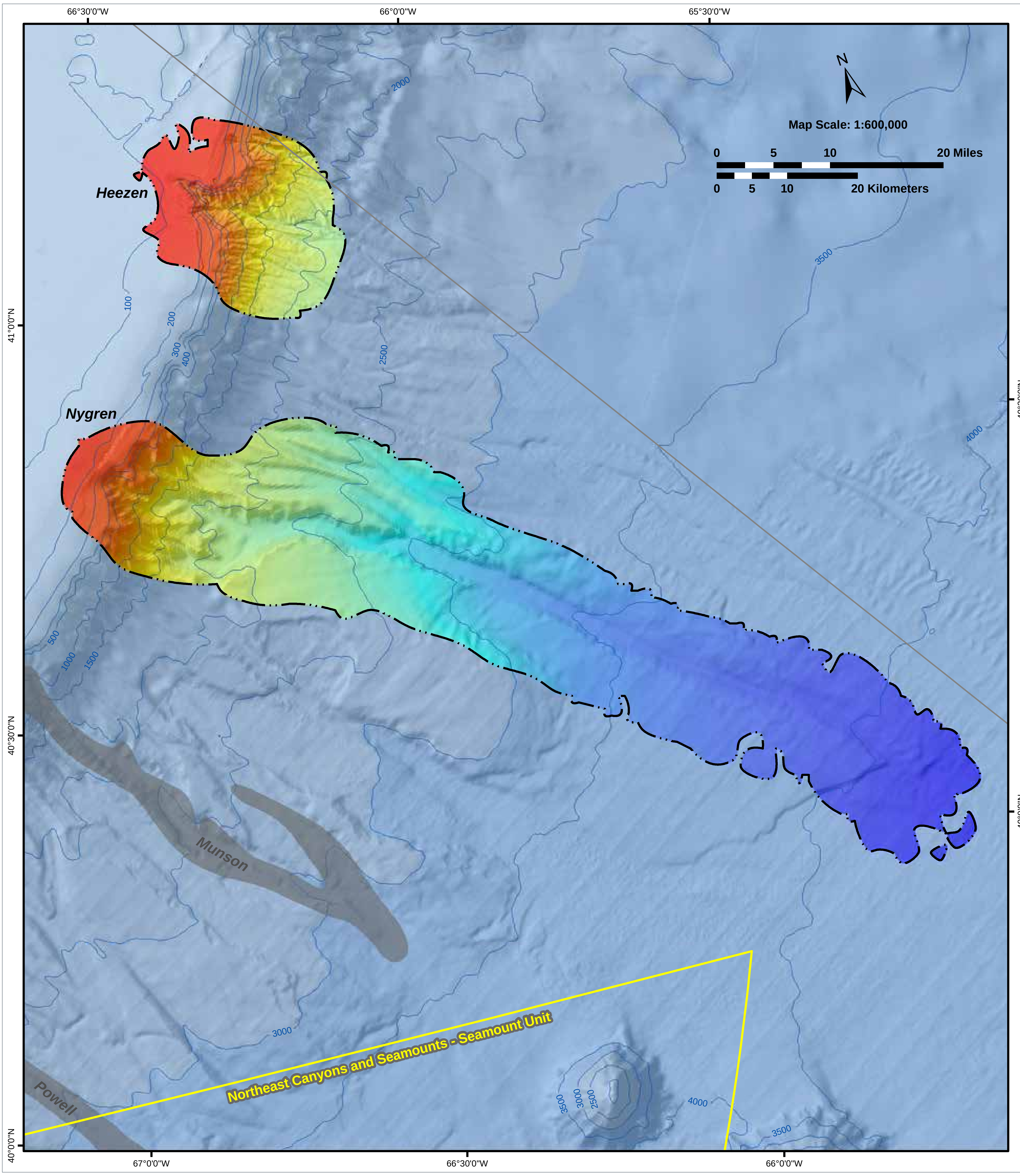
BOEM Bureau of Ocean Energy Management

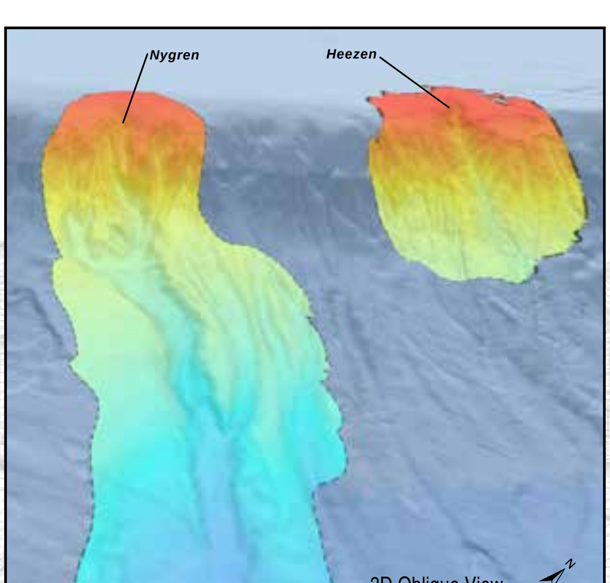
ANKUR PATEL, Contracting Officer
PAUL O. KNORR, Contracting Officer Representative, Study Coordination, Technical Review
ROBERT MARTINSON, Study Initiation and Coordination, Concept Review
KERBY DOBBS, Technical Review GIS
PAULINA CHEN, Technical Editor Review
RUSSELL YERKES, Graphic Art and Layout Review
MARK MUELLER, Technical Review GIS

ATLANTIC CANYONS OVERVIEW



HEEZEN AND NYGREN CANYONS





Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

90 2150 4210

Depth in meters

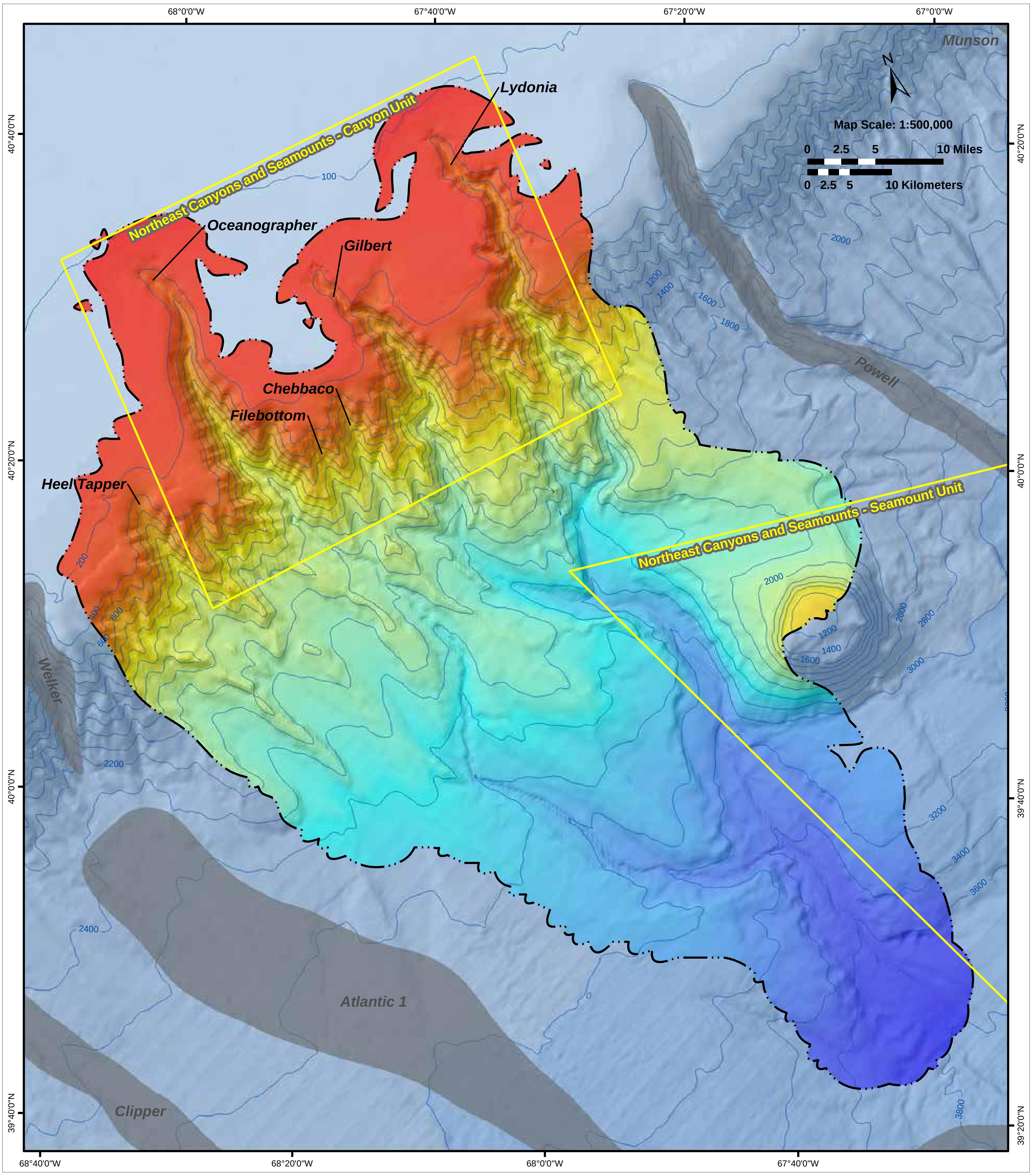
Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

- Heezen Canyon walls are steep and mud covered, with complex terrain of mud ridges, steep gullies, and some exposed bedrock outcrops with occasional glacial erratics (NEFMC and NMFS 2017).
- The NOAA *Okeanos Explorer* documented 18 species of corals inhabiting a depth range of 703 to 1,723 m in Heezen Canyon (Quattrini et al. 2015).
- The walls in Nygren Canyon are suggested to be highly stable due to the presence of Iron-Manganese oxide coating and heavy colonization of attached fauna (Quattrini et al. 2015).
- Nygren Canyon was shown to have the highest species richness compared to other canyons surveyed (Quattrini et al. 2015).
- A possible shipwreck has been identified south of Nygren Canyon in water depths of approximately 3,500 m (CSA et al. 2017).

OCEANOGRAPHER CANYON SYSTEM



	Bathymetric Contour (m)
	National Marine Sanctuary or Monument

Canyon Boundary

	CSA Ocean Sciences Inc. et al. 2019 Delineation Method
	Harris et al. 2014 Delineation Method

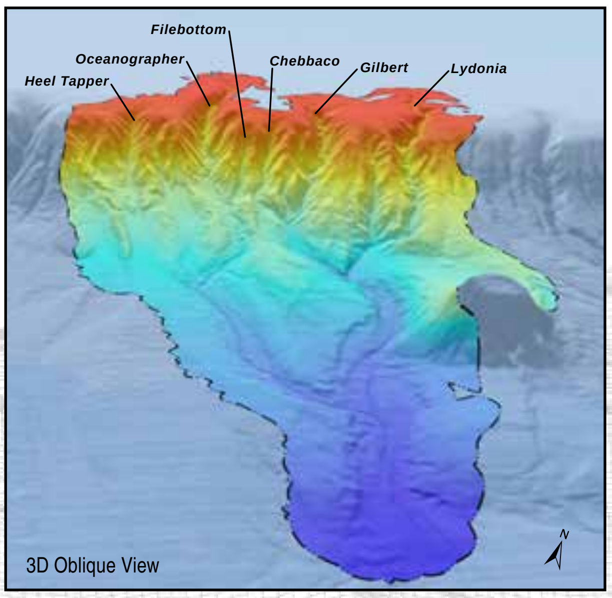
Submarine Canyon Bathymetry

90 1960 3820

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

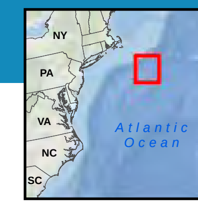


NOTABLE FACTS

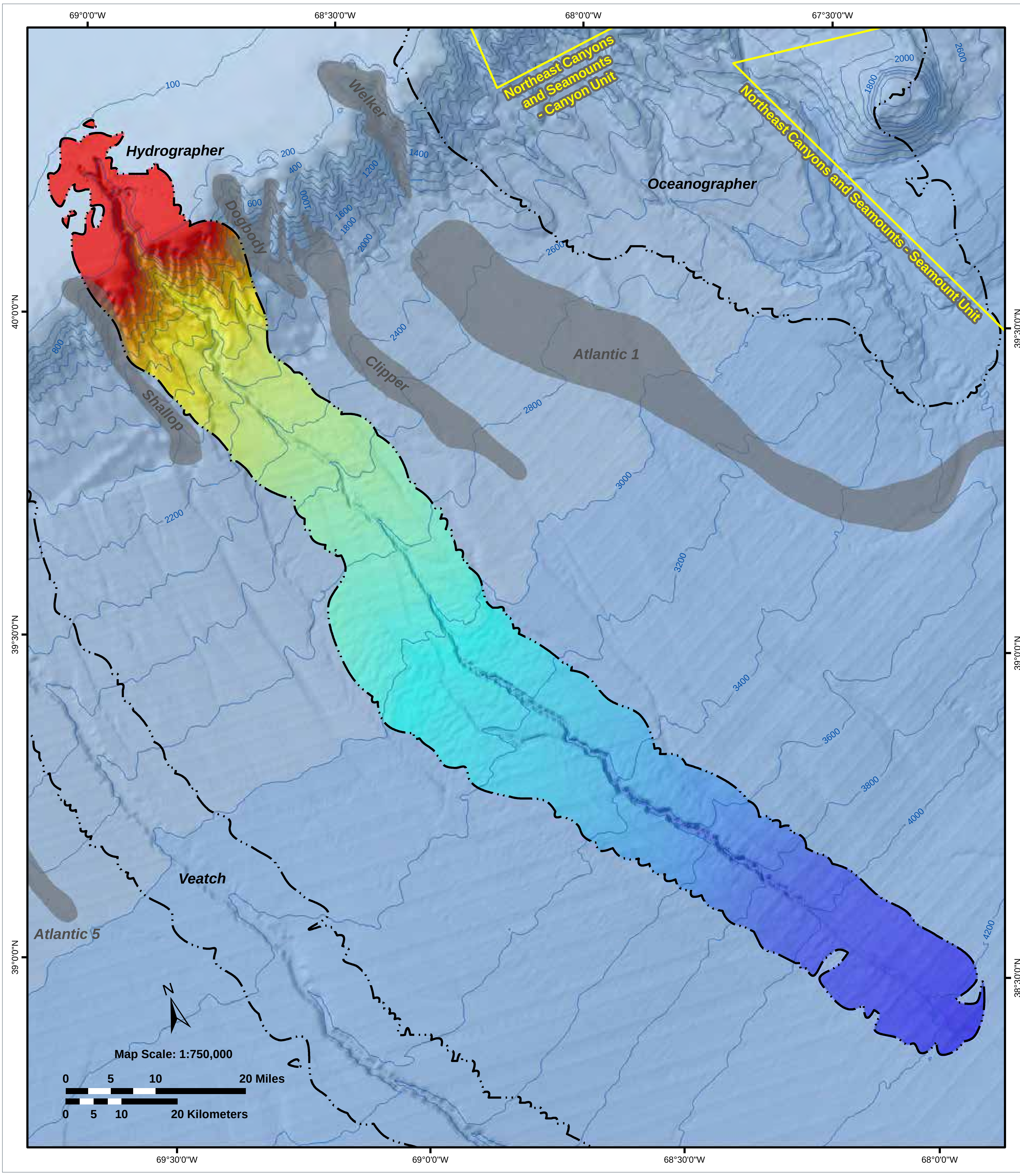
Oceanographer Canyon is deeper than the Grand Canyon (more than 2,000 m deep). The maximum water depth within the entire Oceanographer Canyon system is more than 3,800 m.

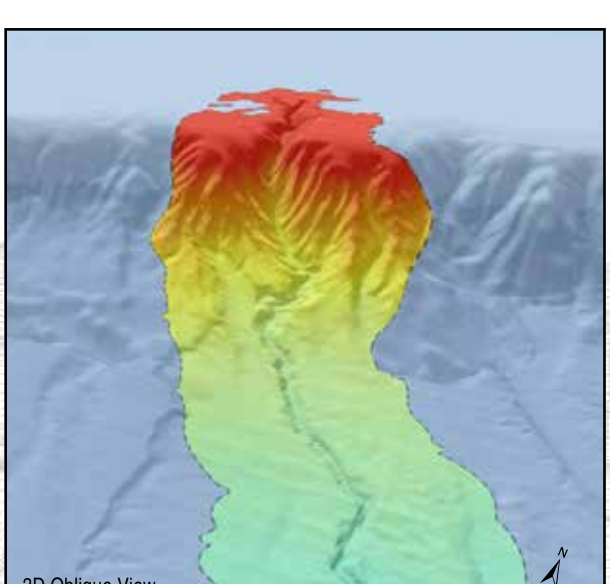
Canyons within the Oceanographer System are known to have a high abundance of fauna, including numerous deep-water corals. A 2013 survey observed a high abundance of fauna living on the underside of ledges, including bivalves, cup corals, squat lobsters, and sponges (Quattrini et al. 2015). In Gilbert Canyon, black corals were discovered for the first time in this area (NEFMC and NMFS 2017).

Lydonia, Oceanographer, and Gilbert Canyons are included in the first and only National Marine Monument to be designated in the Atlantic Ocean (81 FR 65161).



HYDROGRAPHER CANYON





Bathymetric Contour (m)

National Marine Sanctuary or Monument

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

100 — 2200 — 4300

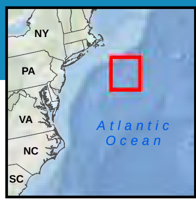
Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

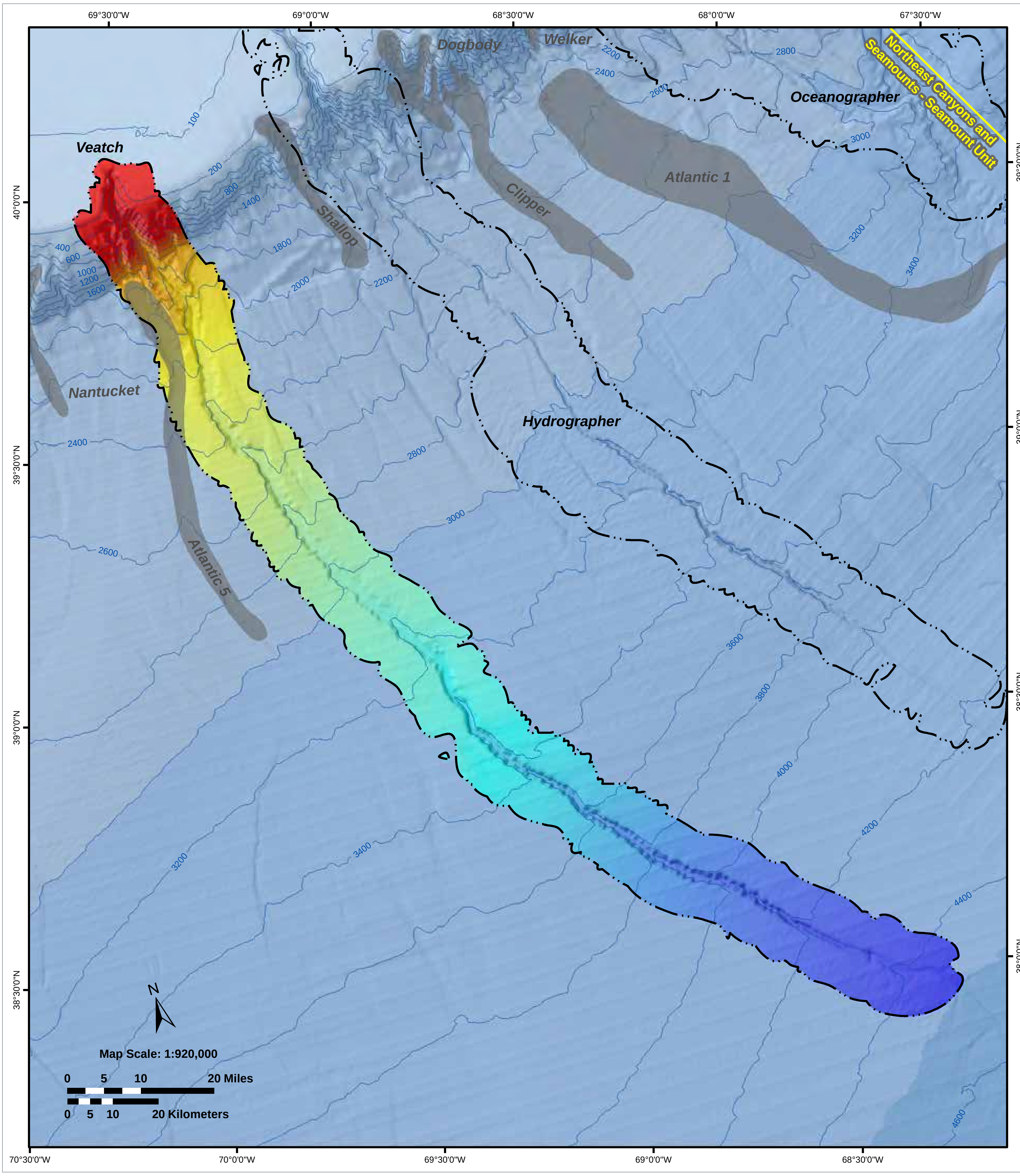
BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

- Siliciclastic and carbonate-rich lithologic sequences are prevalent in this canyon (Quattrini et al. 2015).
- Outcrops in this canyon are most likely of Late Cretaceous to Eocene age (Quattrini et al. 2015).
- A variety of biota have been characterized within the canyon, including eels, cod, dogfish, flounder, crab, corals, sponges, mollusks, shrimps, and cephalopods (Quattrini et al. 2015).
- This canyon is designated as a Habitat Area of Particular Concern (HAPC) based on its unique geomorphology and the presence of deep sea corals (NEFMC and NMFS 2017).



VEATCH CANYON



NOTABLE FACTS

Veatch canyon's formation has been linked to glacial outwash from the George's Bank area (Forde 1981).

Cold seeps and associated biota such as deep sea mussels have been identified in this canyon. Corals and sponges have also been observed living on the canyon walls (NEFMC and NMFS 2017).

This canyon has been designated as a "Tilefish Gear Restricted Area" and is closed to vessels with bottom-tending mobile gear, such as trawls, seines, and dredges (50 CFR 648.297).

Bathymetric Contour (m)

National Marine Sanctuary or Monument

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

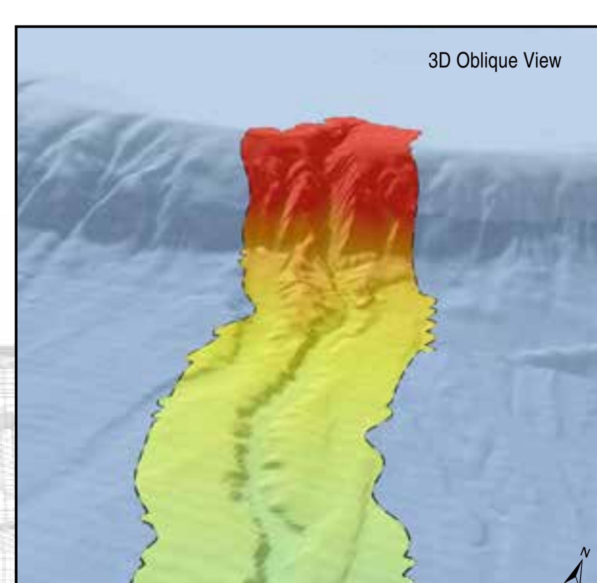
Submarine Canyon Bathymetry

110 2320 4530

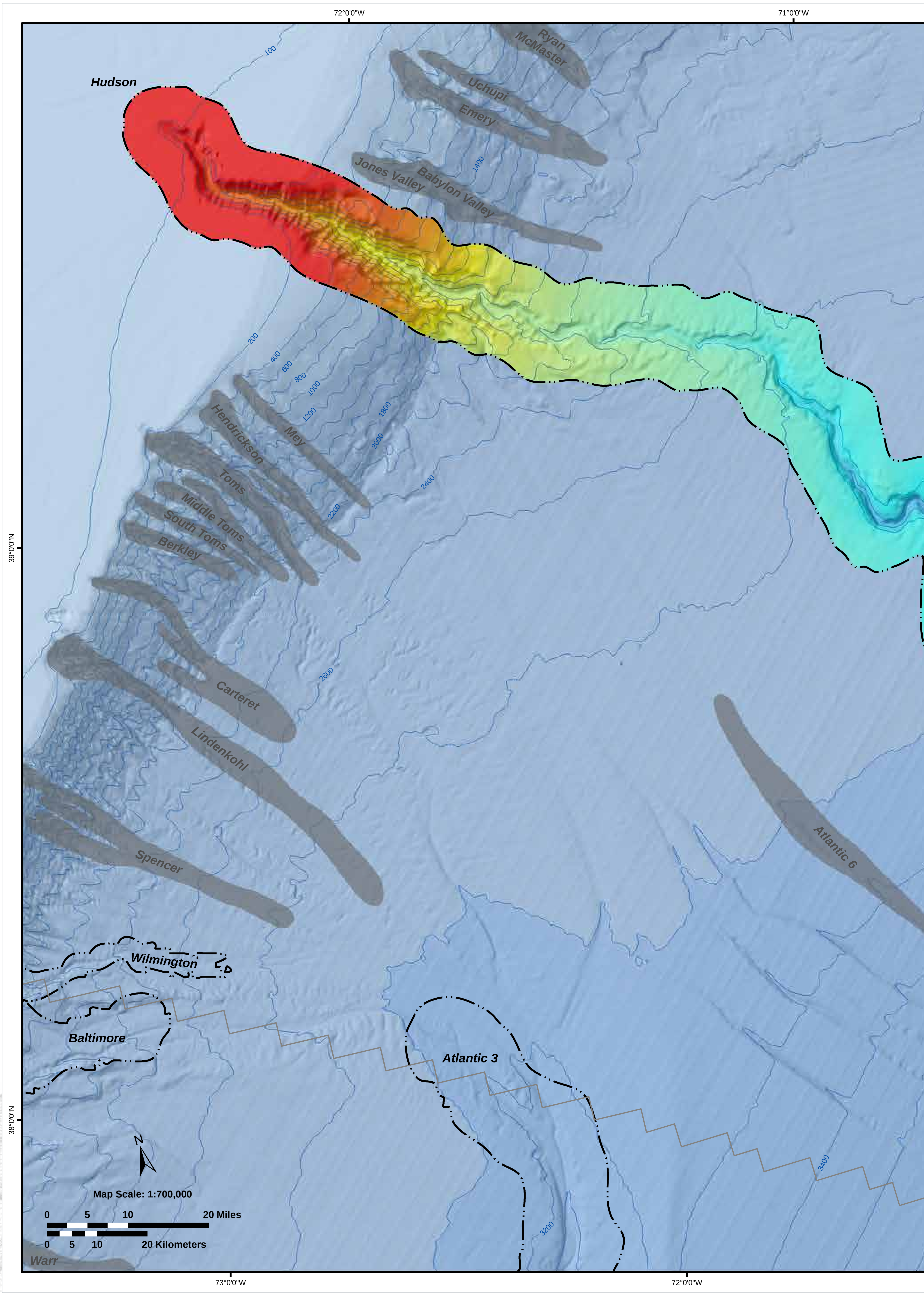
Depth in meters

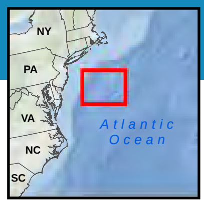
Coordinate System:
USA Contiguous Lambert Conformal Conic

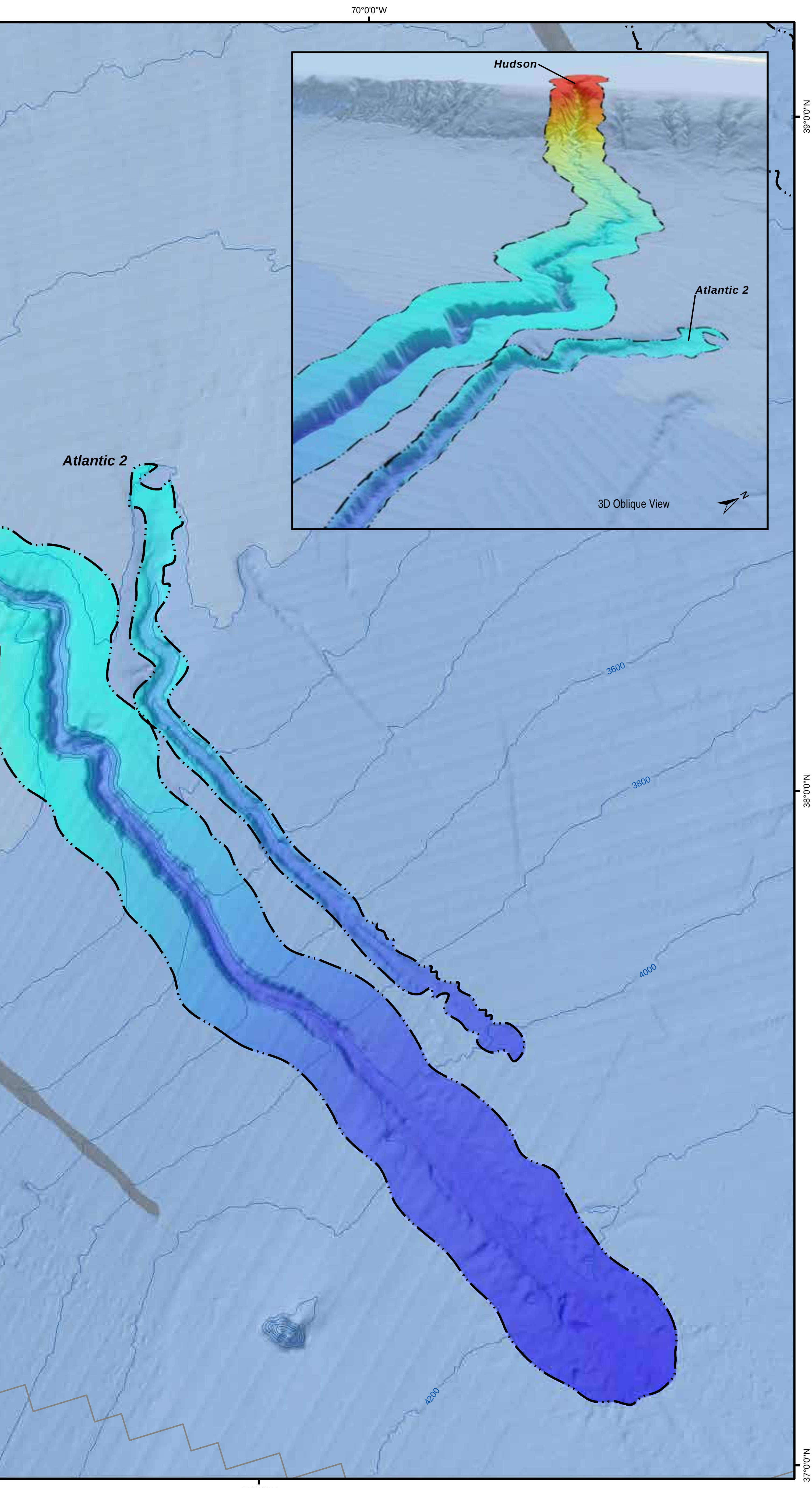
BOEM Bureau of Ocean Energy Management



HUDSON AND ATLANTIC 2 CANYONS







NOTABLE FACTS

Atlantic 2 Canyon runs almost parallel to the southern portion of Hudson Canyon and is approximately 15 km east.

Hudson Canyon is the largest canyon on the U.S. Atlantic shelf and slope (Covault et al. 2011) and is a deep trough that connects the canyon to the mouth of the Hudson River (Lentz et al. 2014).

Hardbottom areas have been identified along the floor of Hudson Canyon, as well as pock-mark fields associated with methane release from sediments (NEFMC and NMFS 2017).

Along the canyon walls near the head of Hudson Canyon, the strata are believed to be of Cretaceous, Paleogene, and Neogene age (Butman et al. 2006).

Sediment transport in Hudson Canyon is primarily driven by tidal currents, internal waves, and storms (Pierdomenico et al. 2017).

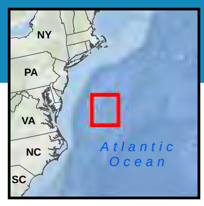
Hudson Canyon, especially its upper reaches, represents an area of enhanced primary productivity and organically rich sediments, which enhances fish and invertebrate communities around the canyon. It is also home to soft coral species in deeper portions of the canyon (Pierdomenico et al. 2017).

Hudson Canyon is recognized as a hotspot for commercial and recreational fishing (Pierdomenico et al. 2017).

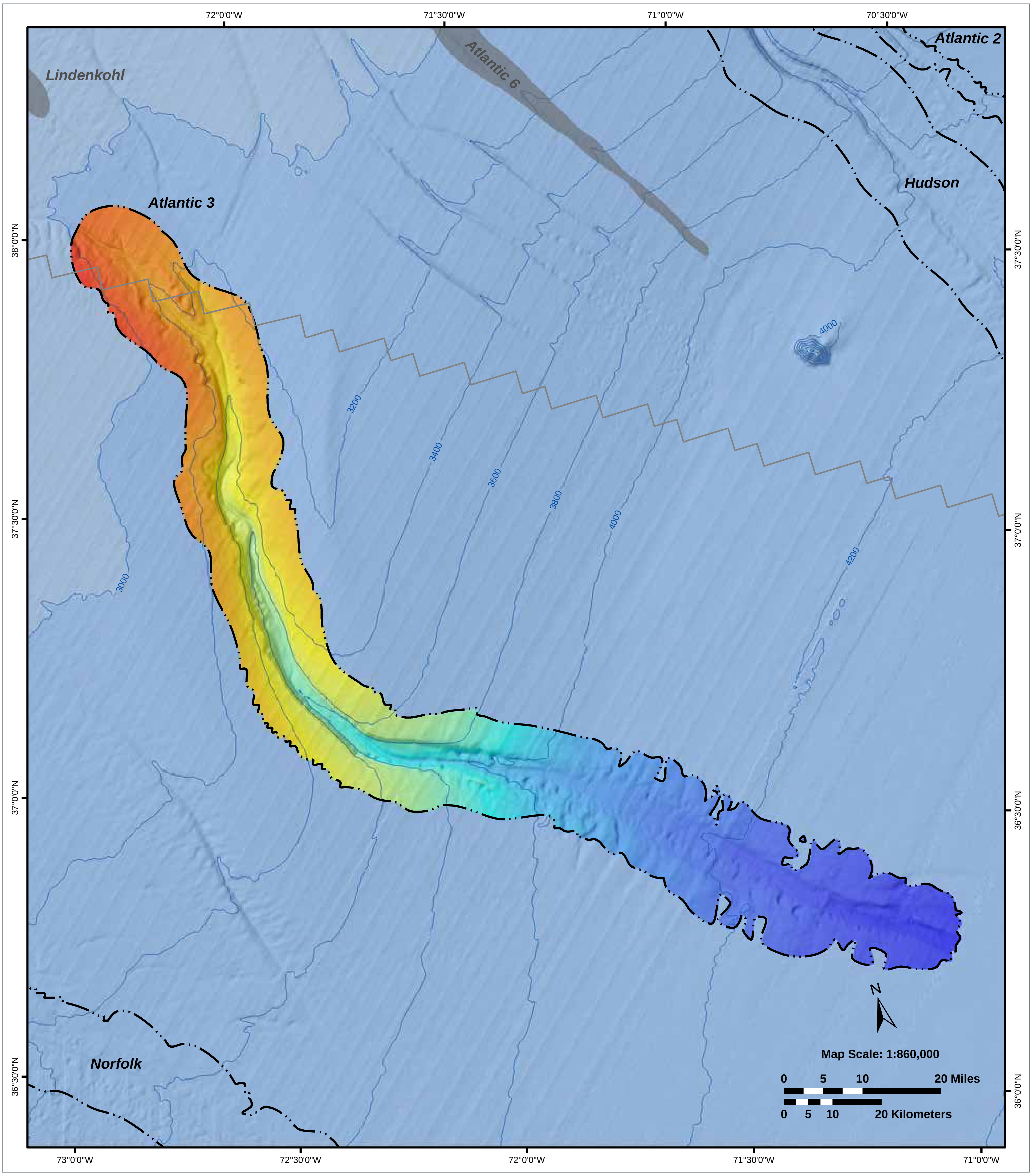
The area adjacent to the head of Hudson Canyon includes a group of shipwrecks, both named and unnamed (NOAA 2019). The morphology of the Hudson Canyon, particularly the north-south orientation of the canyon head and a braided channel near its southeastern outlet, supports archaeological site preservation (Garrison et al. 2012).

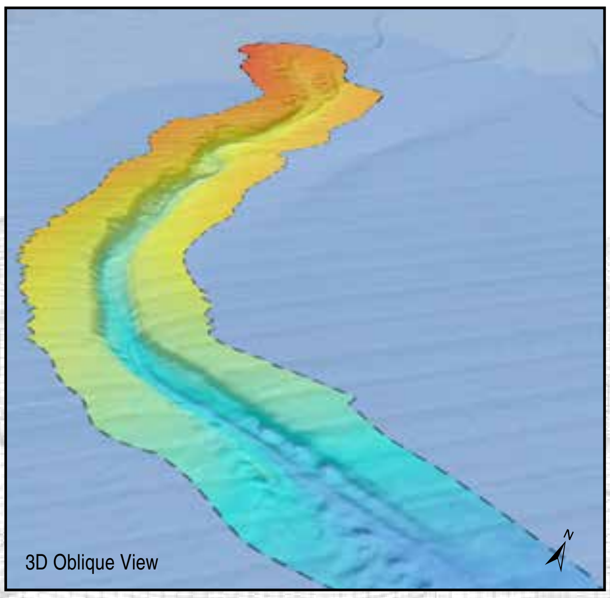
Hudson Canyon has been designated as an HAPC based on its unique geomorphology and the presence of deep sea corals (NEFMC and NMFS 2017).

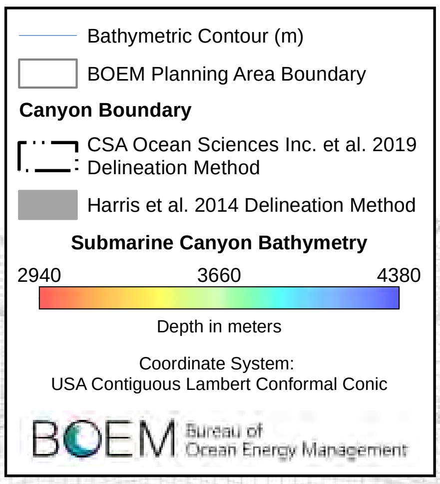
Observations of large seasonal aggregations of krill within Hudson Canyon may also attract marine mammals (Pierdomenico et al. 2017).



ATLANTIC 3 CANYON



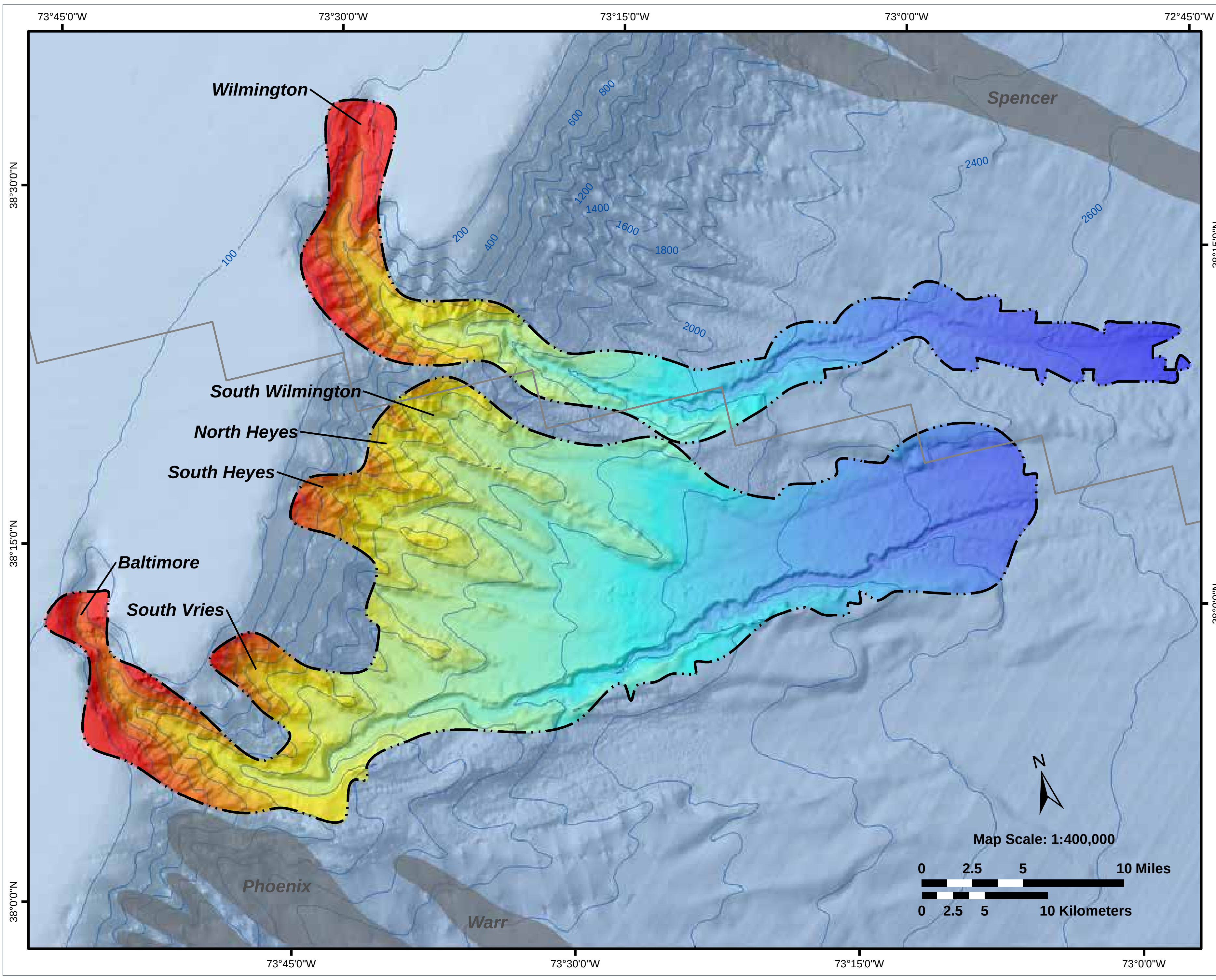


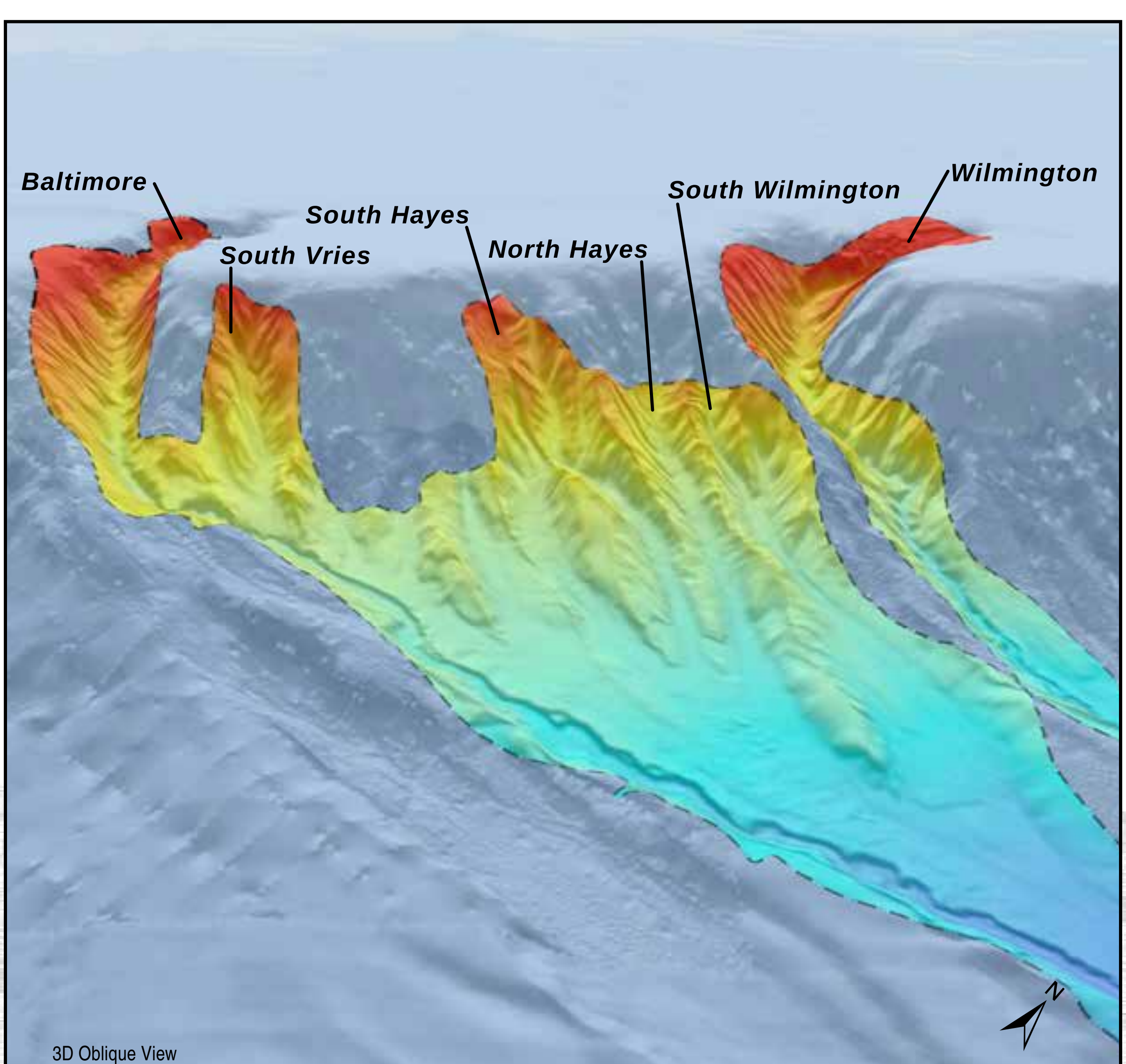


NOTABLE FACTS

- Atlantic 3 Canyon is approximately 240 km long, is located about 333 km east of the Chesapeake Channel in Virginia, and is possibly an extension of the Baltimore Canyon system to the west-northwest.
- There have been four shipwrecks identified adjacent to the Atlantic 3 Canyon edges (NOAA 2019).

WILMINGTON CANYON AND BALTIMORE CANYON SYSTEM





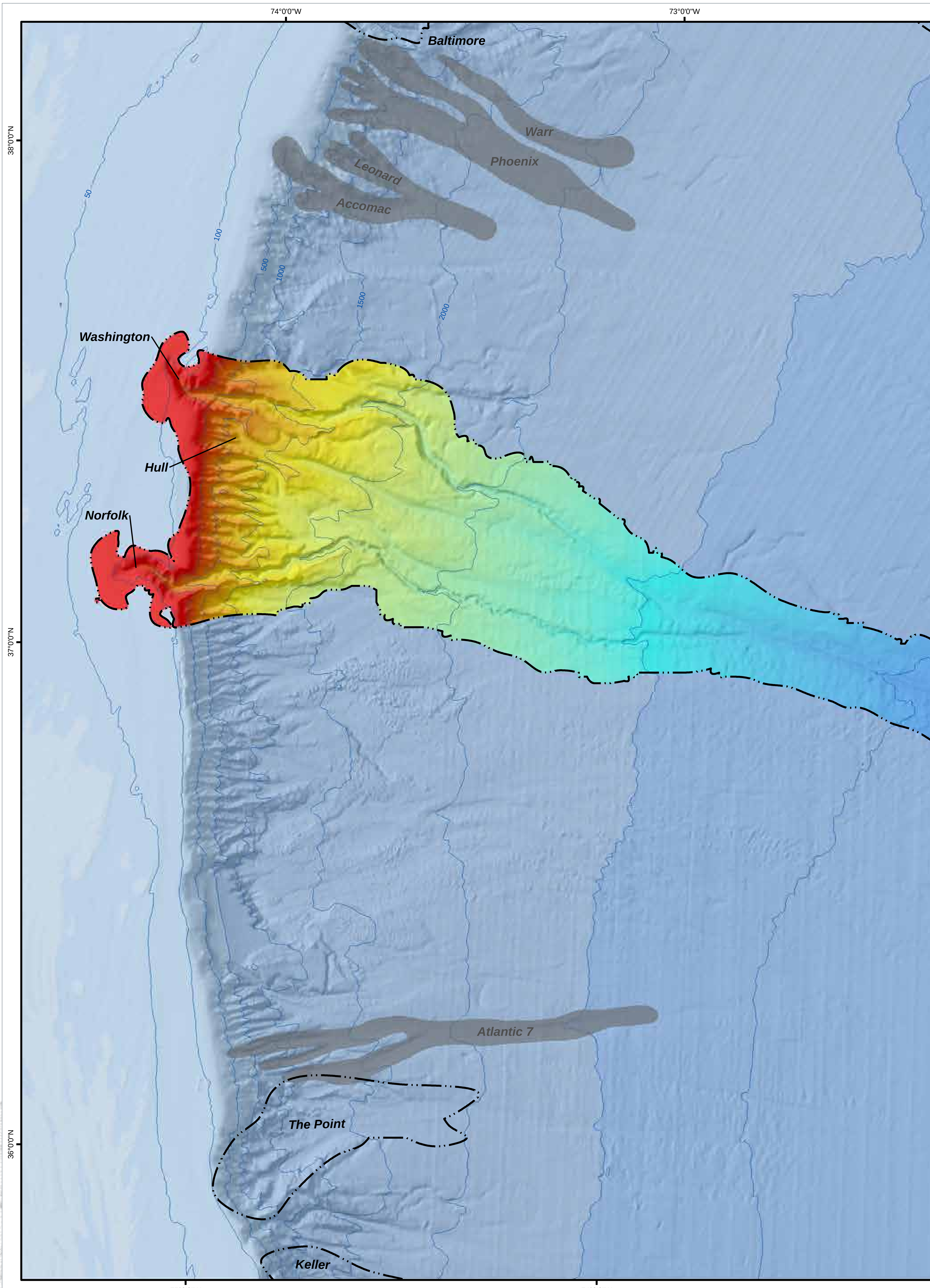
Bathymetric Contour (m)
BOEM Planning Area Boundary
Canyon Boundary
CSA Ocean Sciences Inc. et al. 2019 Delineation Method
Harris et al. 2014 Delineation Method
Submarine Canyon Bathymetry
90 1420 2740
Depth in meters
Coordinate System:
USA Contiguous Lambert Conformal Conic
BOEM Bureau of Ocean Energy Management

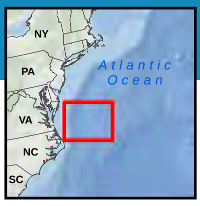
NOTABLE FACTS

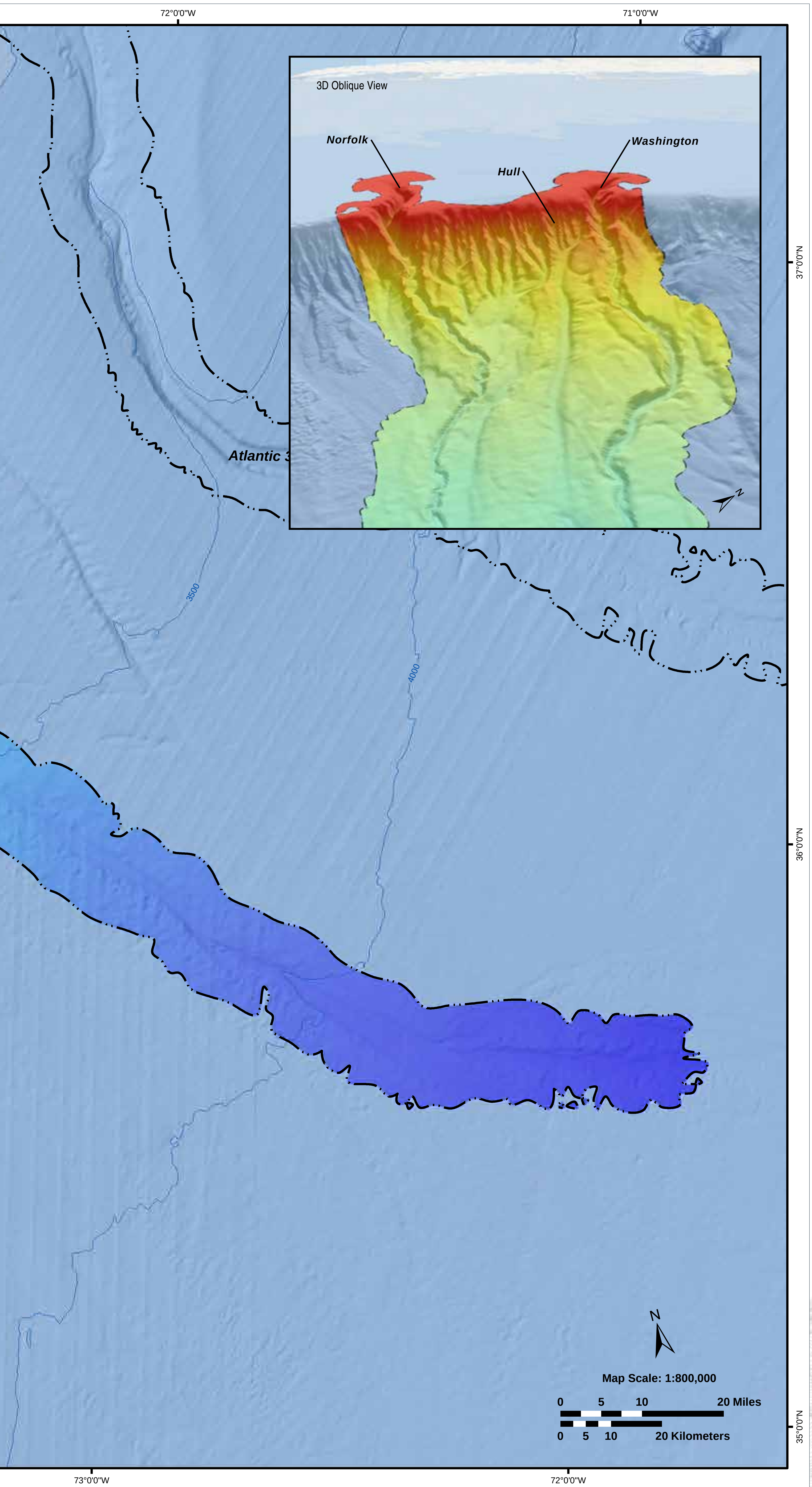
Canyon walls in the upper part of Baltimore Canyon support abundant sessile communities of sponges, anemones, octocorals, and hard corals (Brooke et al. 2017; CSA et al. 2017). Motile fauna, such as crabs, squat lobsters, shrimps, and fishes, are abundant and diverse (Ross et al. 2015; CSA et al. 2017). An active methane seep with associated communities occurs near the southern edge of the canyon (Prouty et al. 2016; CSA et al. 2017).

It was suggested that Wilmington Canyon is older than both South Wilmington and North Heyes Canyons (Kuenzel 2011). A seismic reflection survey suggests that the ancestral Delaware River valley was the most recent of a series of valleys to enter the canyon from the west (McGregor 1981).

NORFOLK CANYON SYSTEM







Bathymetric Contour (m)

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

60 2200 4350

Depth in meters

Coordinate System: USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

The Norfolk Canyon system comprises Norfolk Canyon, Washington Canyon, and the smaller Hull Canyon. The heads of Washington and Norfolk Canyons are approximately 45 km apart and are cut 11.7 km and 19.3 km onto the shelf, respectively (Forde 1981, Obelcz et al. 2014).

Offshore of Washington and Norfolk Canyons' bends, the canyons contain higher densities of steep tributary canyons and gullies, especially along their north walls, which have a greater roughness and local steepness when compared to their southern walls (Obelcz et al. 2014). A series of terraces is characteristic of many places along the walls of Norfolk Canyon (Obelcz et al. 2014).

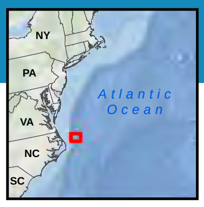
Canyons within the Norfolk Canyon system likely originated from non-riverine erosional processes (Tucholke 1987). Seismic profiles of Washington and Norfolk Canyons indicate an erosional origin of these canyons; however, profiles of the continental slopes reveal a history of alternating episodes of deposition and erosion (Forde 1981).

Currents within the area are largely driven by the shelf-slope front, with current speeds controlled by semidiurnal tides. Current velocities are highest in the heads of the canyon (CSA et al. 2017).

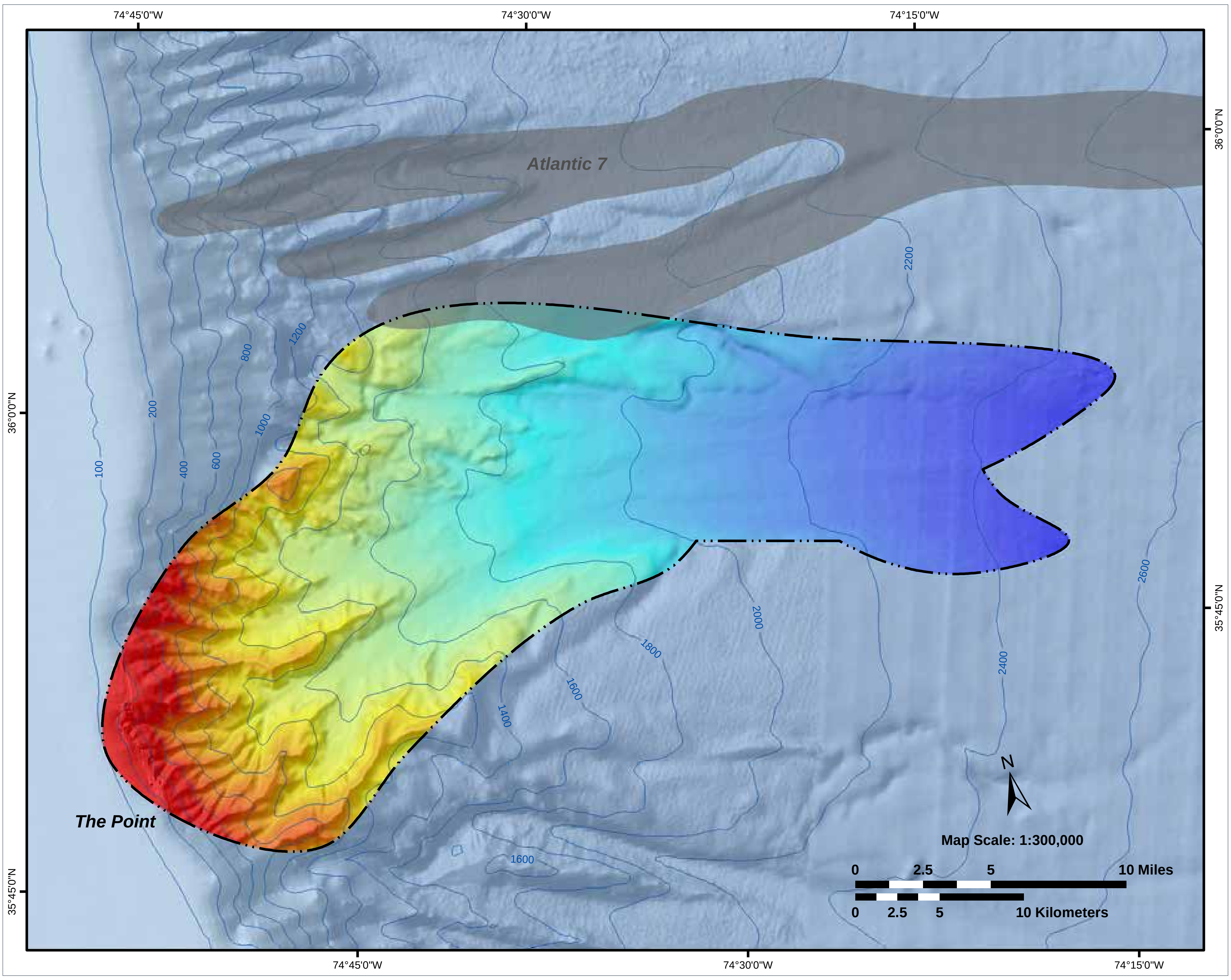
Norfolk Canyon contains known habitats for deep sea, habitat-forming coral species (*Lophelia pertusa*) as well as sessile fauna, such as octocorals, sponges, pink anemones, and soft tube worms (Brooke et al. 2017; CSA et al. 2017). Motile fauna are diverse and abundant and include crabs, squat lobsters, shrimps, and fishes (Ross et al. 2015; CSA et al. 2017). Various investigations of seep sites within, and at the mouth of, Norfolk Canyon have showed active methane seepage.

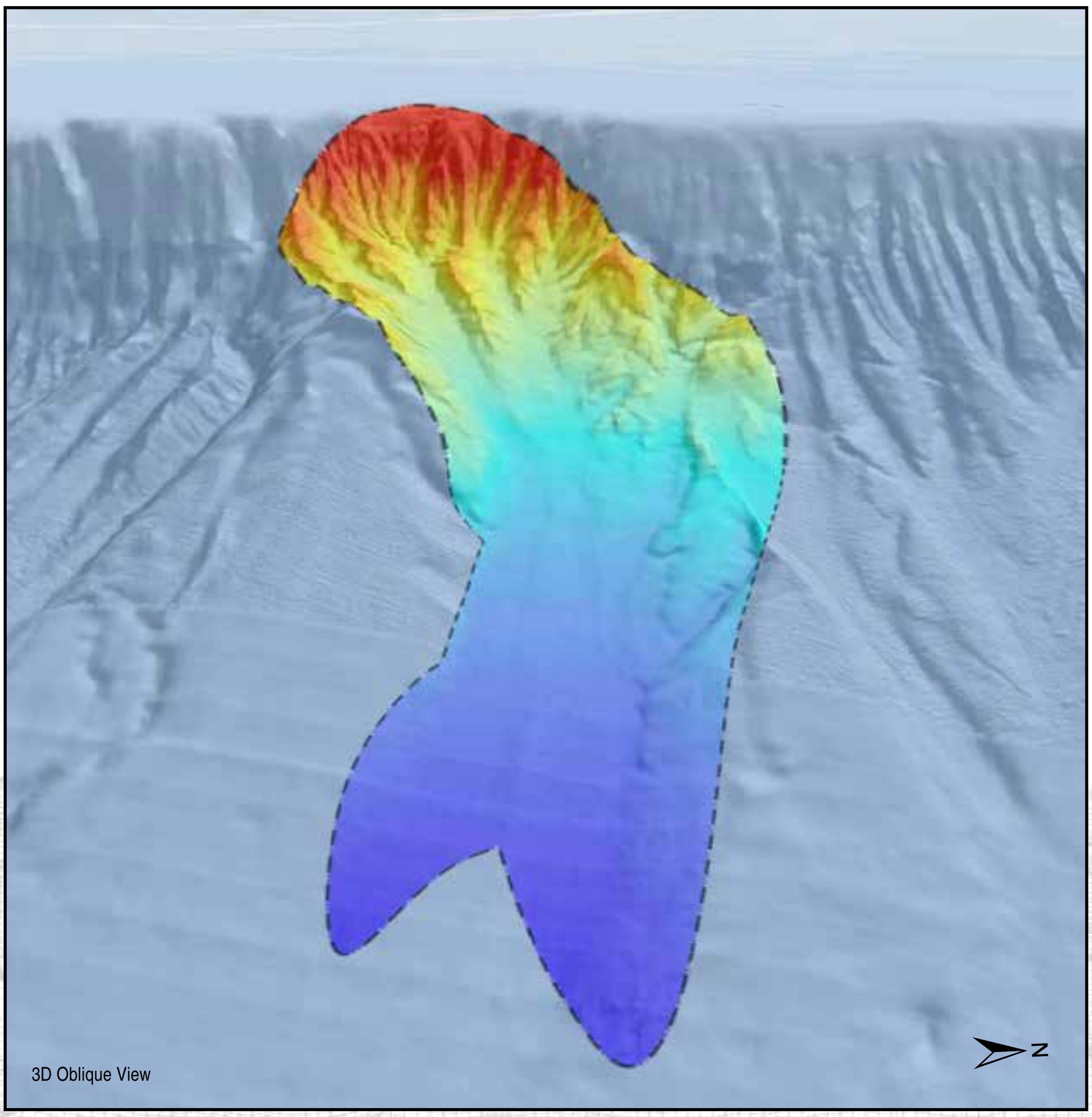
Several shipwrecks have been identified along the shelf edges, near the canyon heads, and along the walls of canyons within the Norfolk Canyon system. Most famous of these are the recently explored "Billy Mitchell" fleet, most of which are located just north of Norfolk Canyon (CSA et al. 2017).

Washington and Norfolk Canyons have been designated as HAPCs based on their unique geomorphology and the presence of deep sea corals (NEFMC and NMFS 2017). Norfolk Canyon has been designated as a "Tilefish Gear Restricted Area" (50 CFR 648.297). It is part of the Frank R. Lautenberg Deep Sea Coral Protection Area.



THE POINT (HATTERAS MIDDLE SLOPE)





Bathymetric Contour (m)

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

100 1300 2510

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

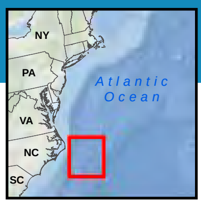
BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

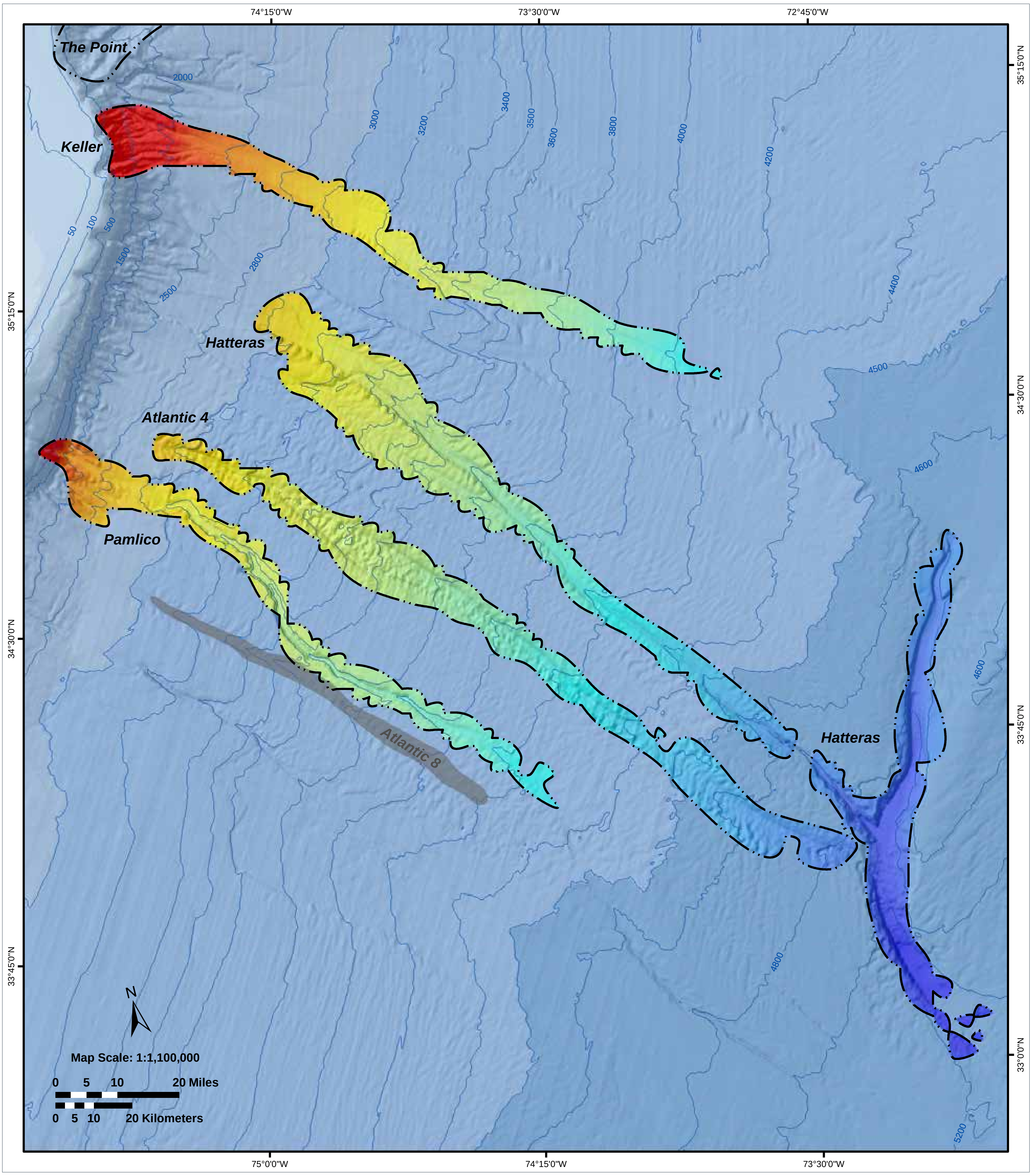
The Point, also referred to as Hatteras Middle Slope (HMS), is a region of numerous, mostly parallel, small canyon or gully features on the continental slope just north of Cape Hatteras.

Investigations documented various unusual conditions on the HMS, including 1) the highest densities of benthic infauna on the U.S. East Coast continental slope; 2) unusual concentrations of benthic fishes and megafaunal invertebrates; 3) reduced species richness, motility, and sizes in fish community, perhaps related to environmental conditions; and 4) an exceptionally high flux of organic carbon to the bottom (Schaff et al. 1992; Hecker 1993; Sulak and Ross 1996).

Atlantic Ocean waters along the North Carolina coast have been the scene of an unusually large number of shipwrecks, and this area often is referred to as the "Graveyard of the Atlantic."



KELLER, HATTERAS, ATLANTIC 4, AND **PAMLICO** CANYONS



NOTABLE FACTS

The *San Delfino*, believed to have sunk in 1942, was identified near the head of Keller Canyon in a water depth of approximately 50 to 70 m (Hoyt et al. 2014).

Hatteras Canyon has deep valleys that cut across the upper continental rise, which terminates on the lower rise in fans characterized by transverse sediment waves (Gardner et al. 2005).

Many organisms have been observed in Hatteras Canyon, indicating a highly productive area. Bacterial mats were present, but higher order chemosynthetic organisms were not observed (Raineault et al. 2018).

The rock faces within Pamlico Canyon host a number of organisms, including sea spiders, cup coral, skates, cusk eels, octopus, red crabs, spider crabs, and brittle stars (Raineault et al. 2018).

Bathymetric Contour (m)

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

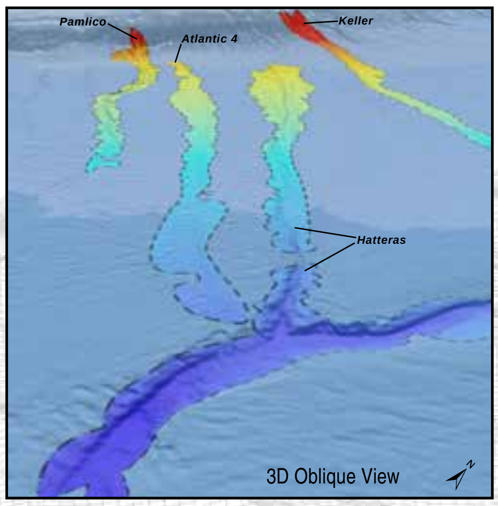
Submarine Canyon Bathymetry

130 2730 5330

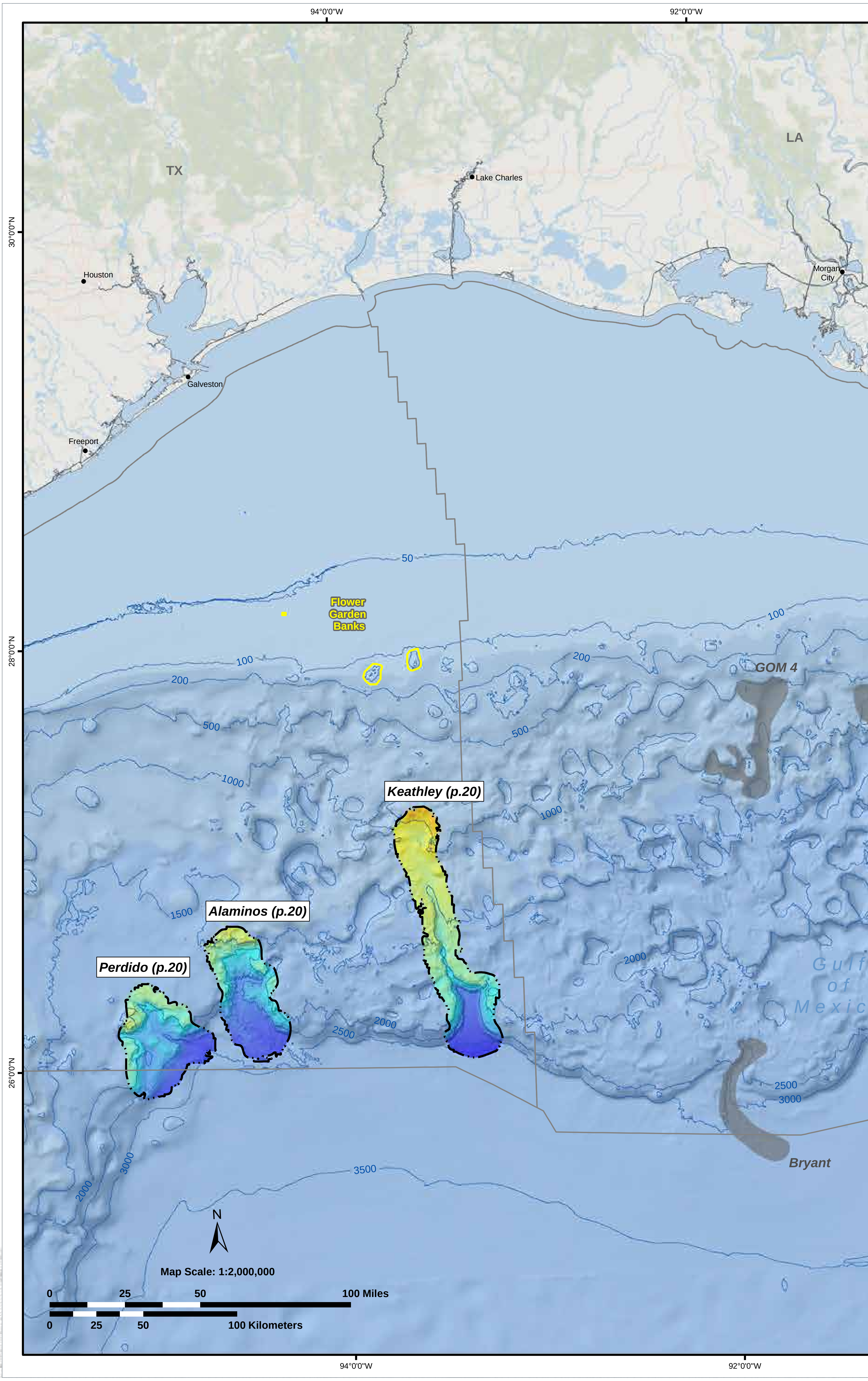
Depth in meters

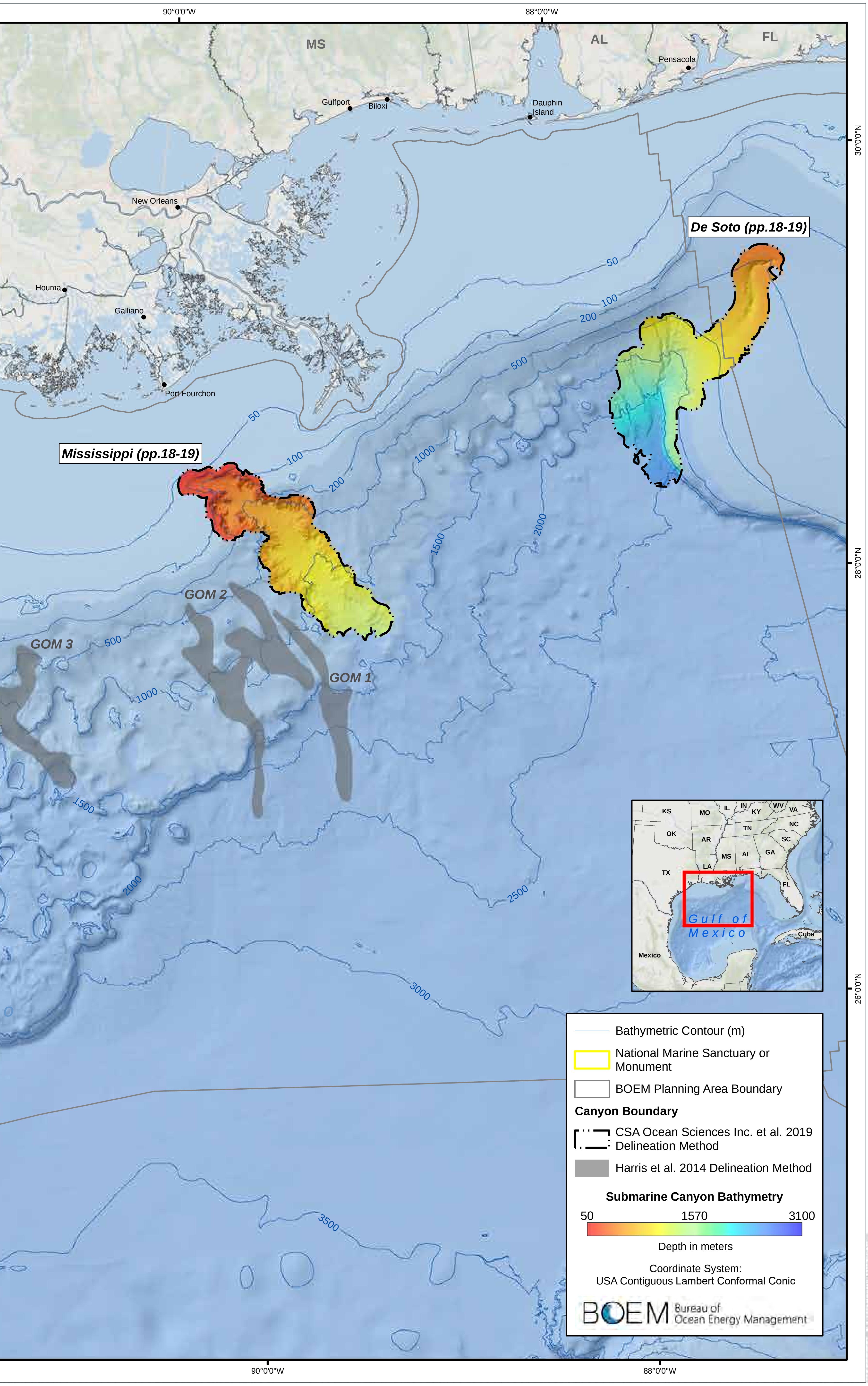
Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

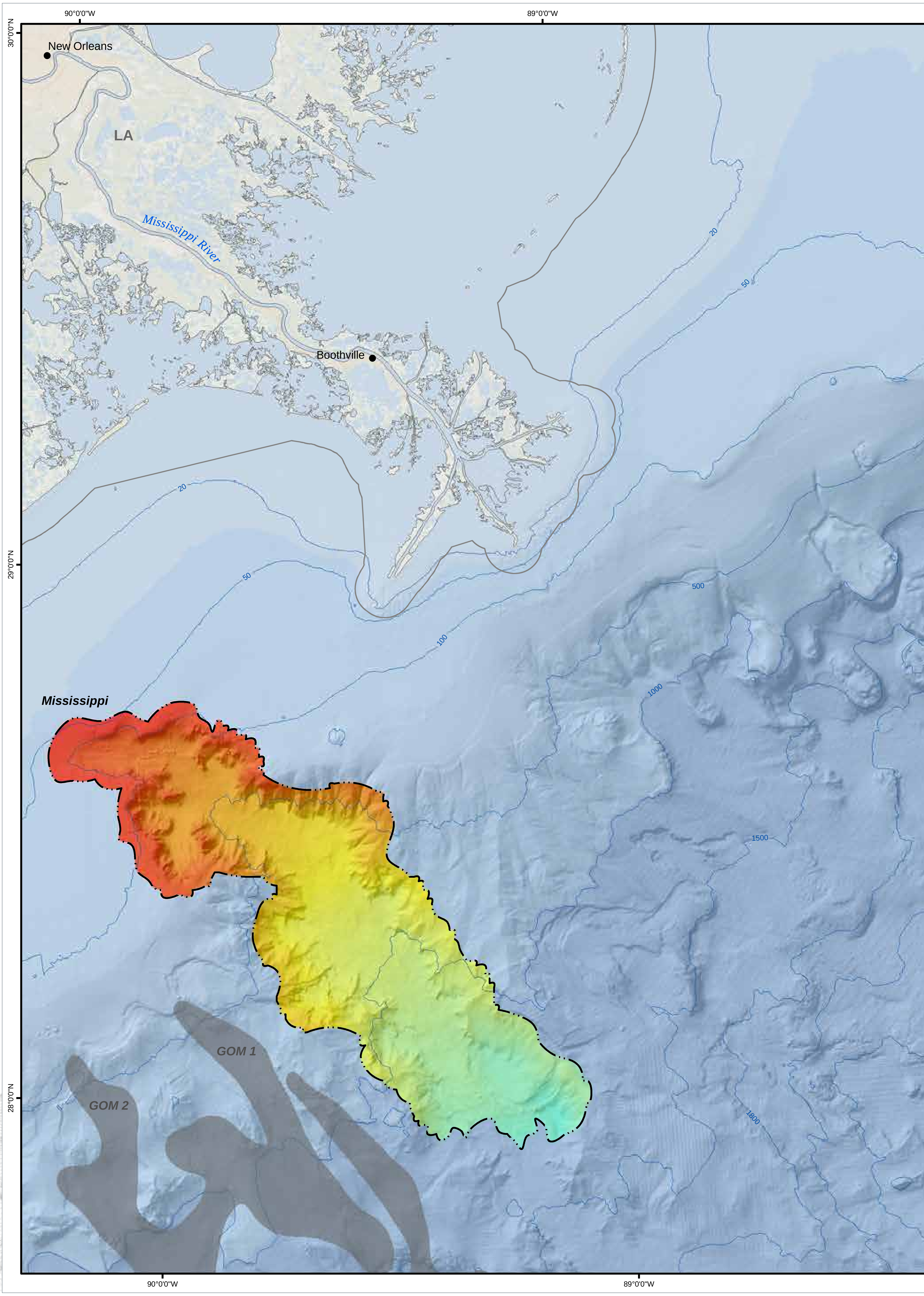


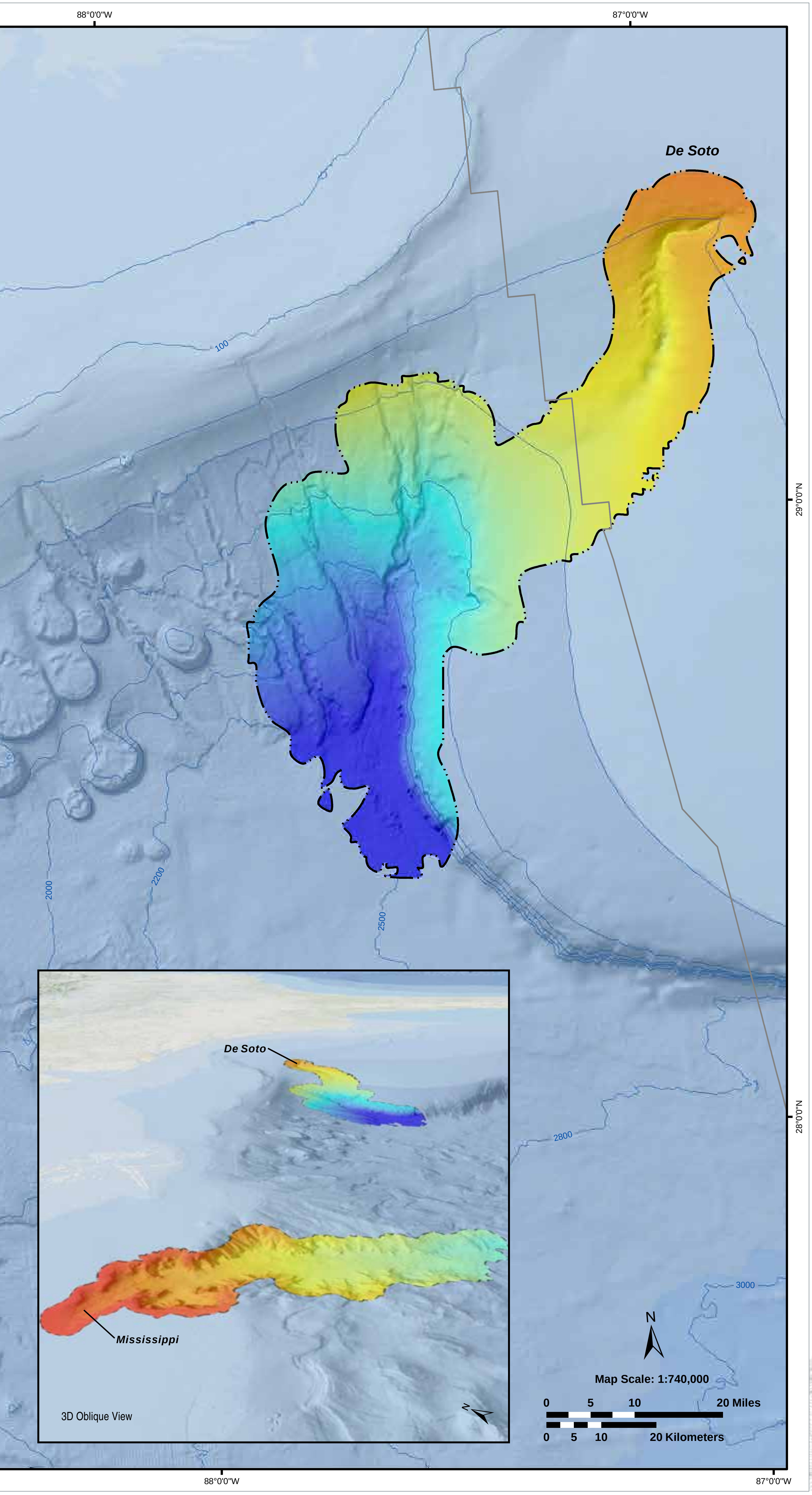
GULF OF MEXICO CANYONS OVERVIEW

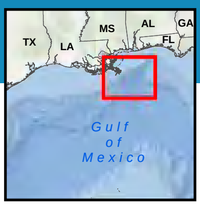



90°0'0"W
88°0'0"W
MS
AL
FL
Pensacola
Gulfport
Biloxi
Dauphin Island
New Orleans
Houma
Galliano
Port Fourchon
30°0'0"N
28°0'0"N
26°0'0"N
De Soto (pp.18-19)
Mississippi (pp.18-19)
GOM 1
GOM 2
GOM 3
50
100
200
500
1000
1500
2000
2500
3000
3500
KS
MO
IL
IN
KY
WV
VA
OK
AR
TN
NC
SC
MS
AL
GA
LA
TX
FL
Gulf of Mexico
Cuba
Mexico
Bathymetric Contour (m)
National Marine Sanctuary or Monument
BOEM Planning Area Boundary
Canyon Boundary
CSA Ocean Sciences Inc. et al. 2019 Delineation Method
Harris et al. 2014 Delineation Method
Submarine Canyon Bathymetry
50
1570
3100
Depth in meters
Coordinate System:
USA Contiguous Lambert Conformal Conic
BOEM Bureau of Ocean Energy Management

MISSISSIPPI AND DE SOTO CANYONS

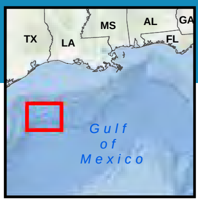




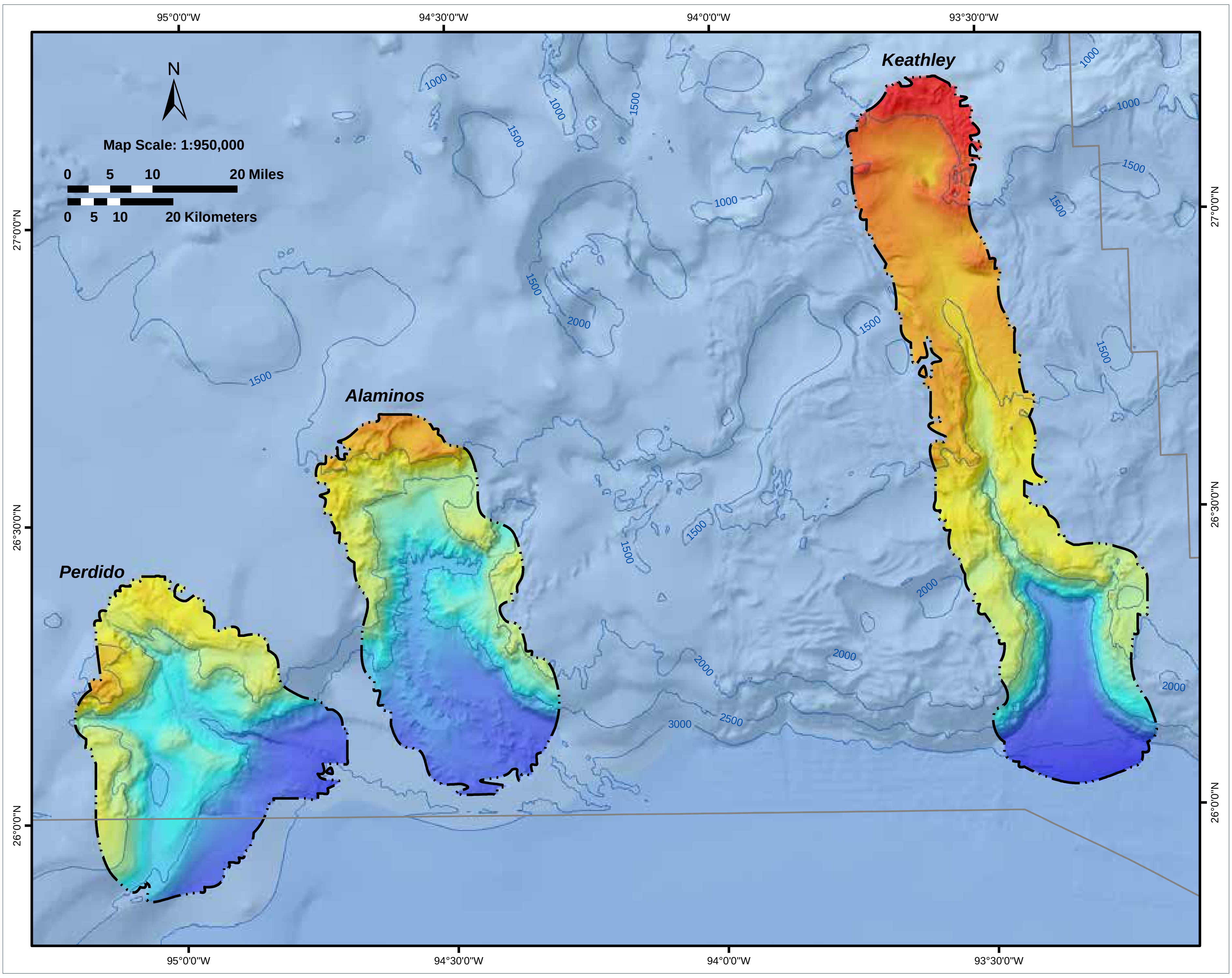


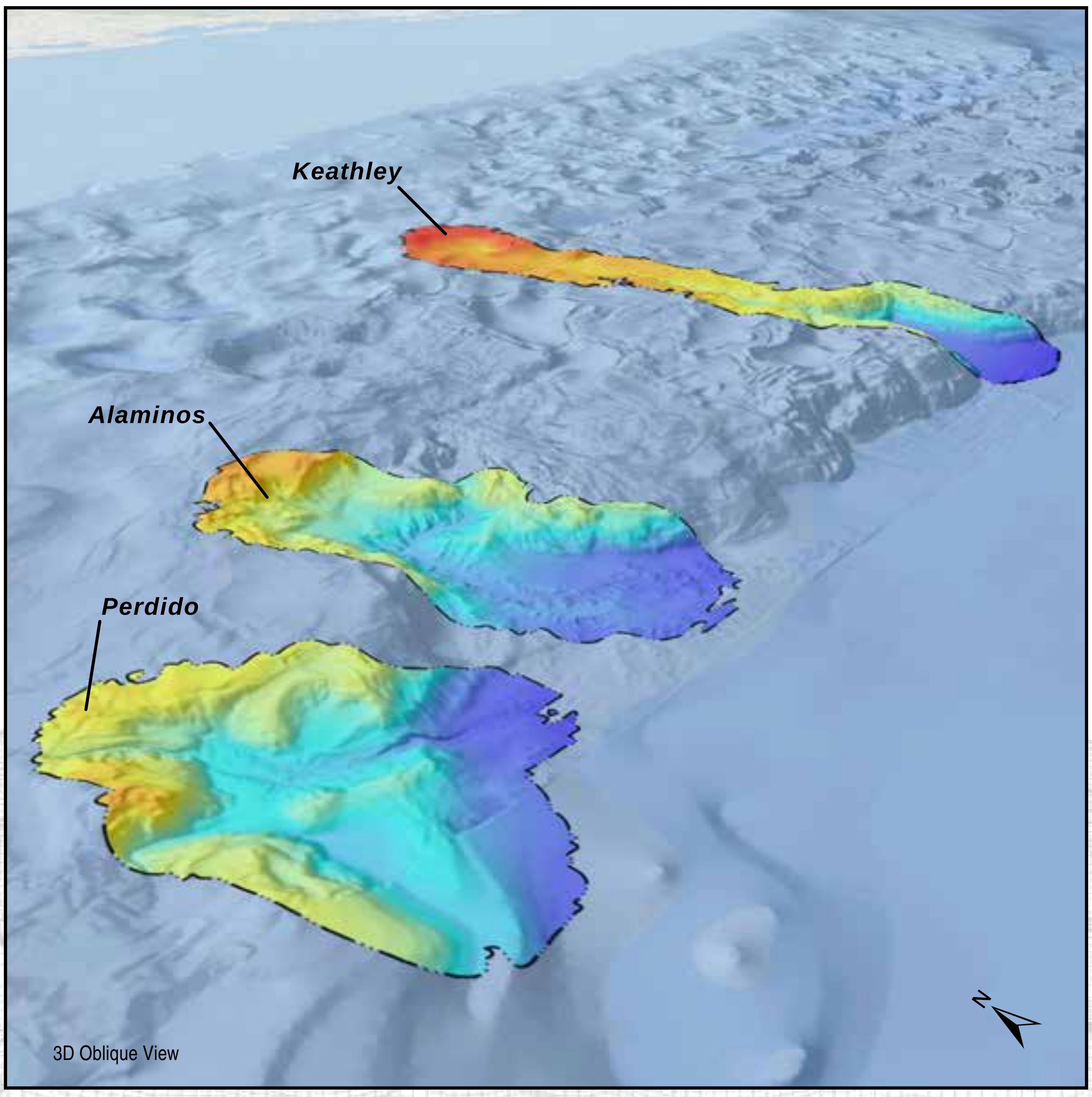
NOTABLE FACTS

- The origin of Mississippi Canyon is generally thought to have been attributed to channel entrenchment of the Mississippi River during low stands of sea level and erosion (Coleman et al. 1982).
- Currents in the upper Mississippi Canyon generally oscillate up/down canyon in twelve-hour time intervals and are bottom-intensified (Ross et al. 2009).
- Mississippi Canyon is an important avenue for sediment transport and organic carbon input from the Mississippi River to the deep sea in the Gulf of Mexico (Wei et al. 2010).
- Organic matter transport through Mississippi Canyon supports an abundant biological community that includes numerous polychaete and fish species (Wei et al. 2010, 2012).
- The *Mica* Wreck, dated to the first half of the 19th century, is located in Mississippi Canyon in 808 m of water. The 20-m long vessel is well preserved with low sedimentation, allowing for identification of its wooden hull and metal sheathing, and recovery of a variety of artifacts (Krivor et al. 2011).
- De Soto Canyon is thought to have formed in the Late Cretaceous period, and although its exact formation is uncertain, recent studies indicate the topographically induced eddies shed off of the Loop Current may have contributed to the modern-day shape (Dunn 2016).
- Considerable nutrient enrichment and enhanced primary production occurs at the head of De Soto Canyon during periods of high regional river discharge (Jochens et al. 2002).
- Approximately 52 species of fishes have been observed in De Soto Canyon, based on pooled trawl data from 1964 to 2002 (Wei et al 2012). De Soto Canyon is near the Pinnacle Trend, a high-relief area of carbonate mounds with unique biological communities.
- The head of De Soto Canyon is within the year-round Biologically Important Area for the endangered Gulf of Mexico Bryde's whale (*Balaenoptera edeni*) (LaBrecque et al. 2015).



PERDIDO, ALAMINOS, AND KEATHLEY CANYONS





Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

800 1890 3100

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

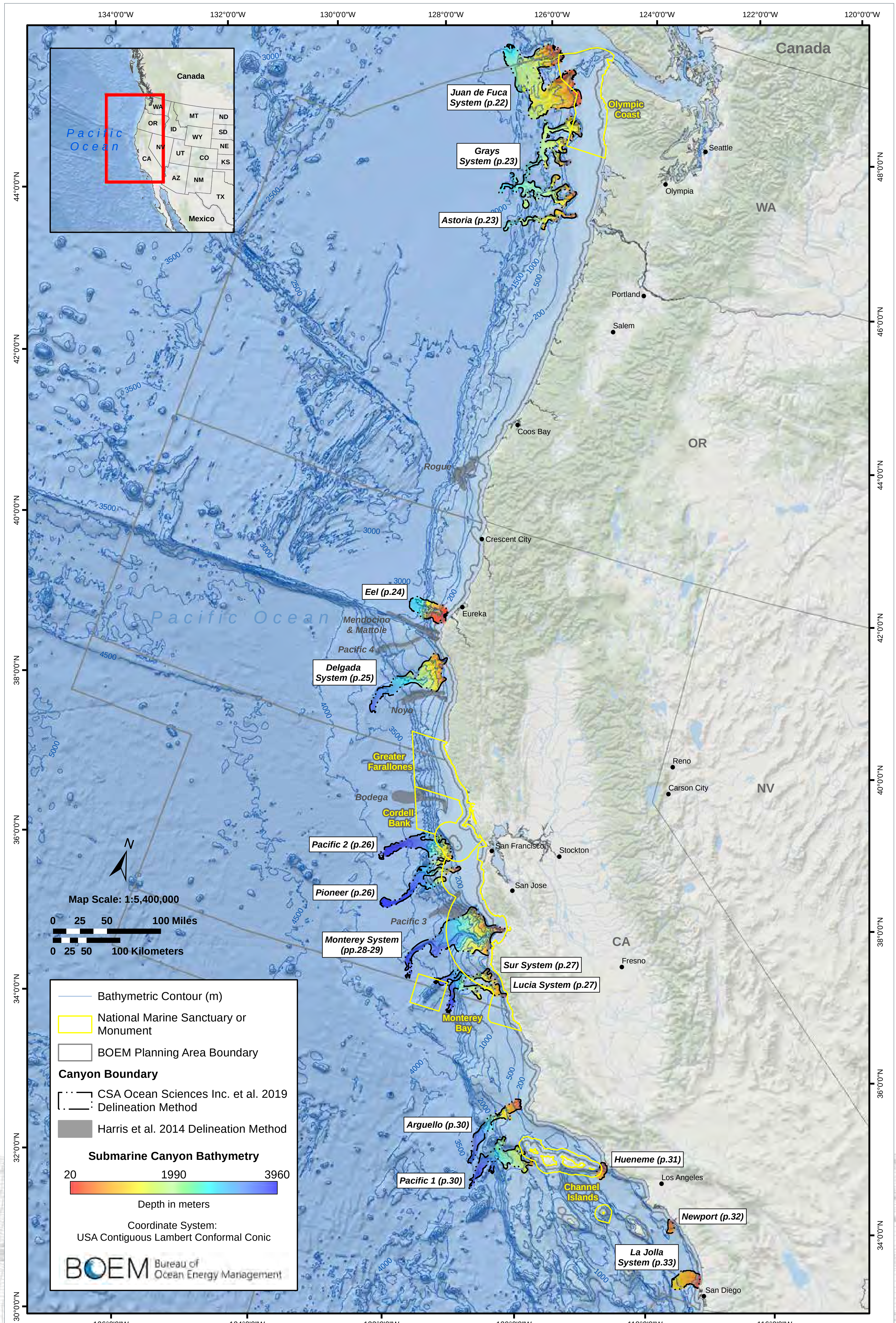
A deep cyclonic boundary current along the Sigsbee and Perdido escarpments has been observed, showing that the flows below the escarpments are more vigorous than above it (Donohue et al. 2008).

The area around Perdido and Alaminos Canyons has been recognized for decades as having a high potential for petroleum and is considered an important ultra deep water source for both U.S. and Mexico (Fiduk et al. 1999).

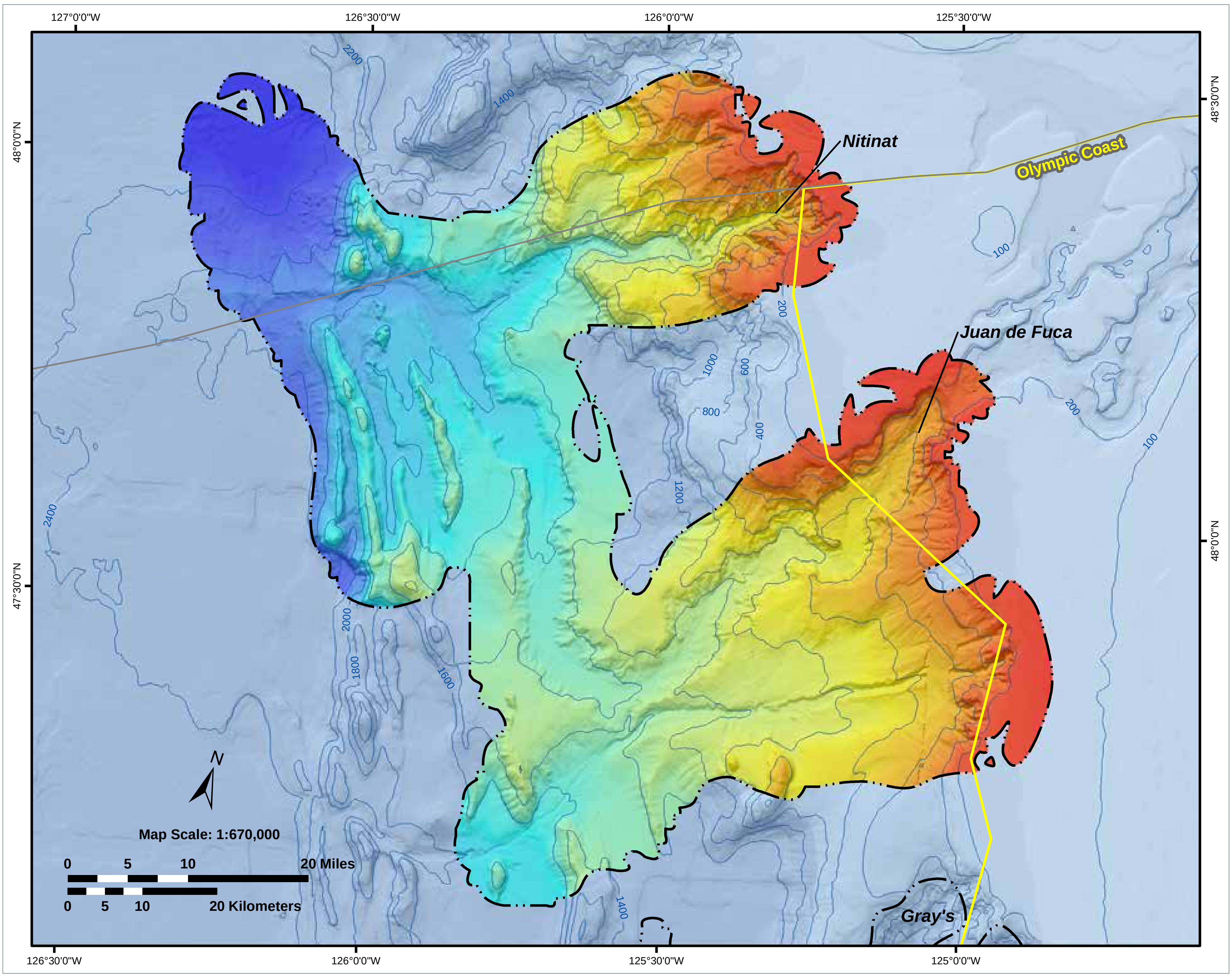
Chemosynthetic organisms, including species of gastropods, crustaceans, echinoderms, gorgonians, fishes, and their related carbonate deposits have been identified within the Alaminos Canyon area (Roberts et al. 2007).

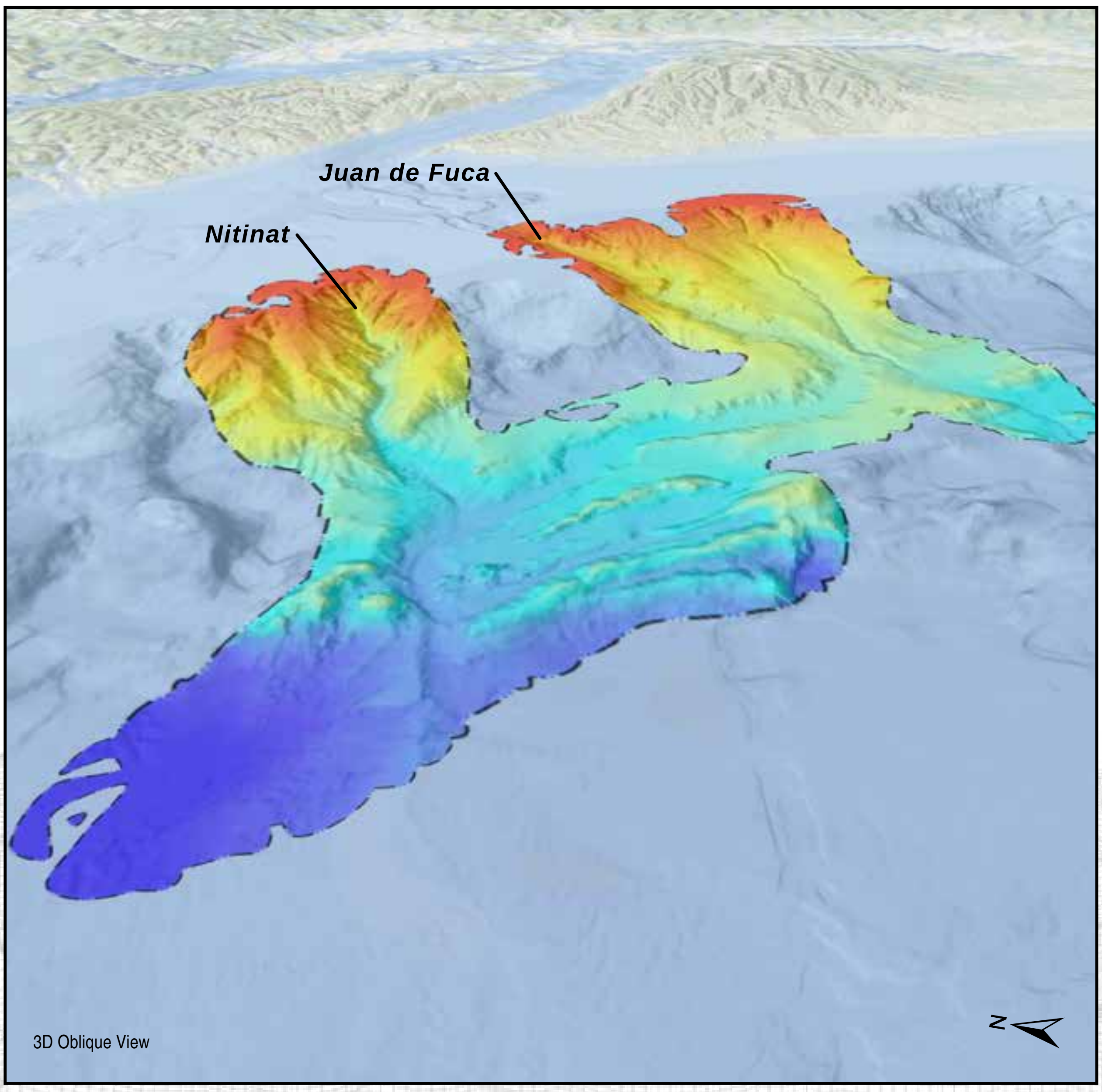
The origin of Keathley Canyon began with underlying lateral salt movement beneath the upper canyon, uplifting the continental slope and raising and coalescing the sediments, resulting in a valley-like feature with walls of uplifted and deformed strata (Lee et al. 1992).

PACIFIC CANYONS OVERVIEW



JUAN DE FUCA CANYON SYSTEM





3D Oblique View

Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

120 1330 2540

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

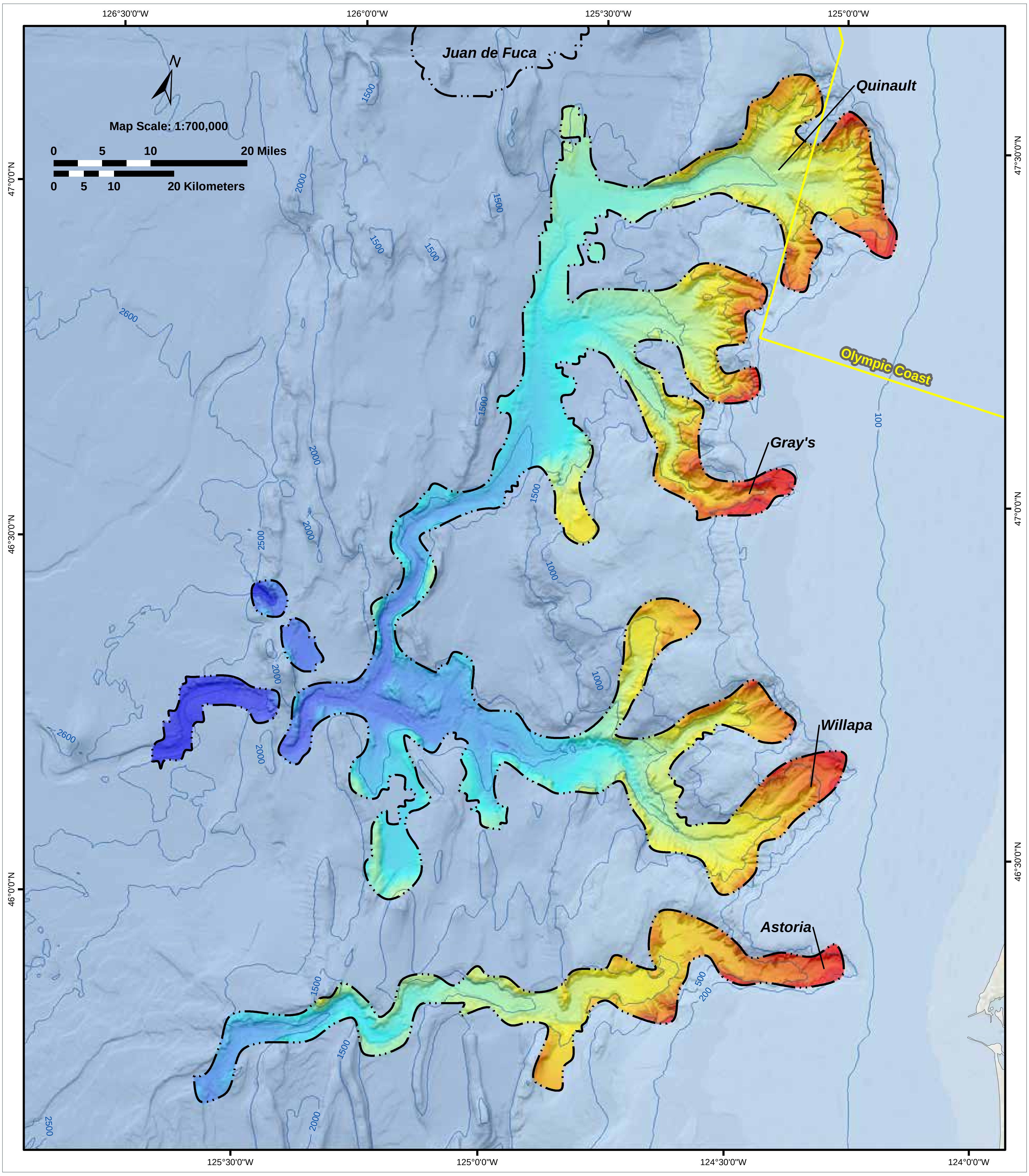
Juan de Fuca Canyon has been identified as the most important source for the net upwelling of nitrate onto the Washington shelf (Hickey and Banas 2008). The canyon is also known to have high krill biomass concentration (Santora et al. 2018).

Large deep-sea communities were discovered in Juan De Fuca Canyon in 2017, including long-lived species of coral and sponges (Raineault et al. 2018).

The trawling fleet in Washington focuses their efforts around the Juan de Fuca Canyon to catch rockfish, Pacific hake, arrowtooth flounder, and Dover sole (Tagart 1997).

The *Coast Trader* was sunk in 1942 by a Japanese submarine, and the shipwreck lies at the head of Juan de Fuca Canyon (NOAA 2019).

GRAY'S CANYON SYSTEM AND ASTORIA CANYON



NOTABLE FACTS

- The Gray's Canyon system's influence over regional flow may facilitate transport of zooplankton species from the canyon onto the continental shelf, which benefits fish species by providing prey (Peterson et al. 2010).
- Astoria Canyon, the largest canyon offshore Oregon, has been shaped by periodic major earthquakes and sea level changes (Embley 2010).
- Benthic and pelagic communities of Astoria Canyon have been described in Bosley et al. (2004), with overall productivity linked with the canyon's physical circulation.
- Astoria Canyon is a popular fishing spot because its unique underwater geography upwells nutrients near the mouth of the Colombia river, providing a food source for fish (Whittaker 2019).

Bathymetric Contour (m)
National Marine Sanctuary or Monument
BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

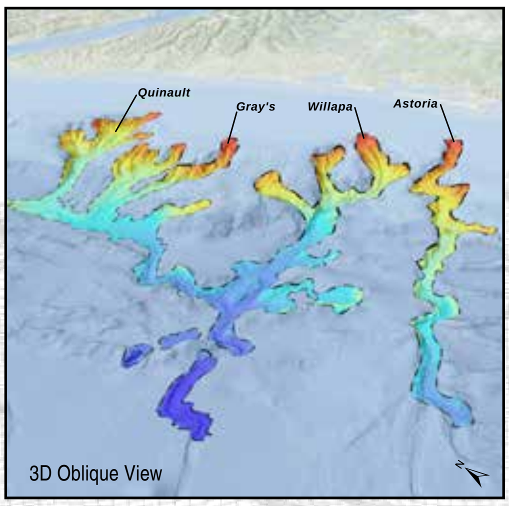
Submarine Canyon Bathymetry

190 1430 2660

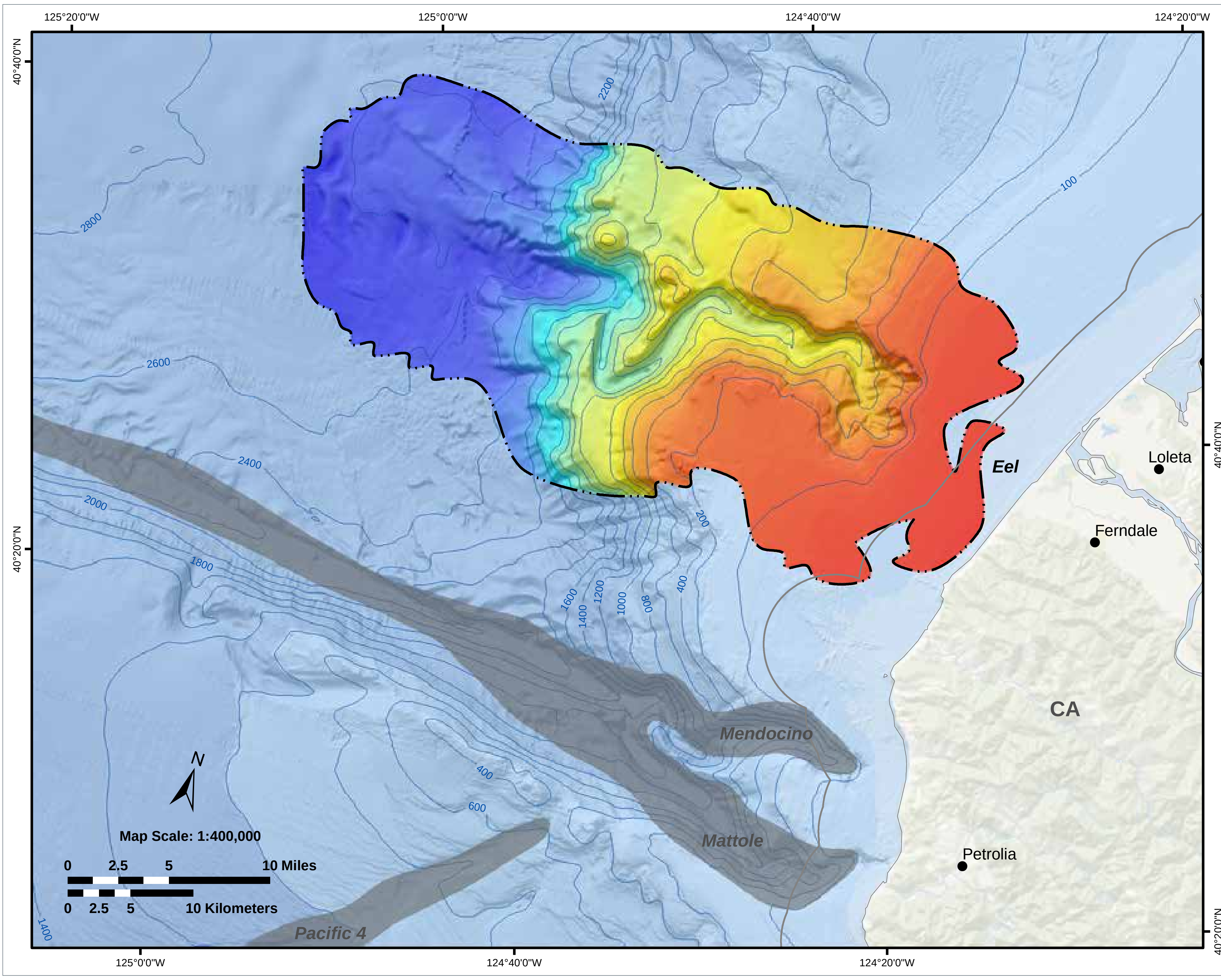
Depth in meters

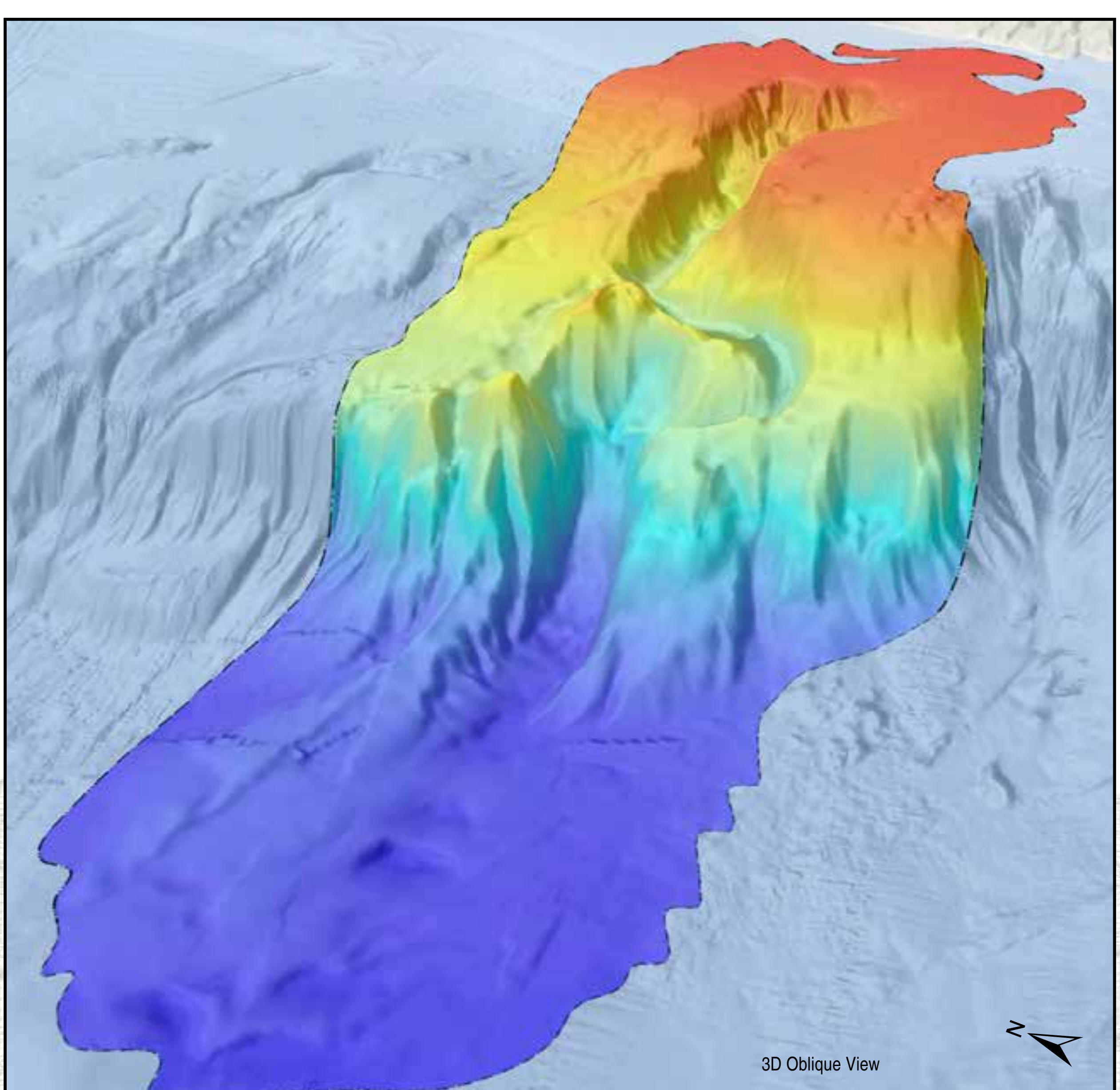
Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management



EEL CANYON





Bathymetric Contour (m)
BOEM Planning Area Boundary
Canyon Boundary
CSA Ocean Sciences Inc. et al. 2019 Delineation Method
Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry
20 1380 2730
Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

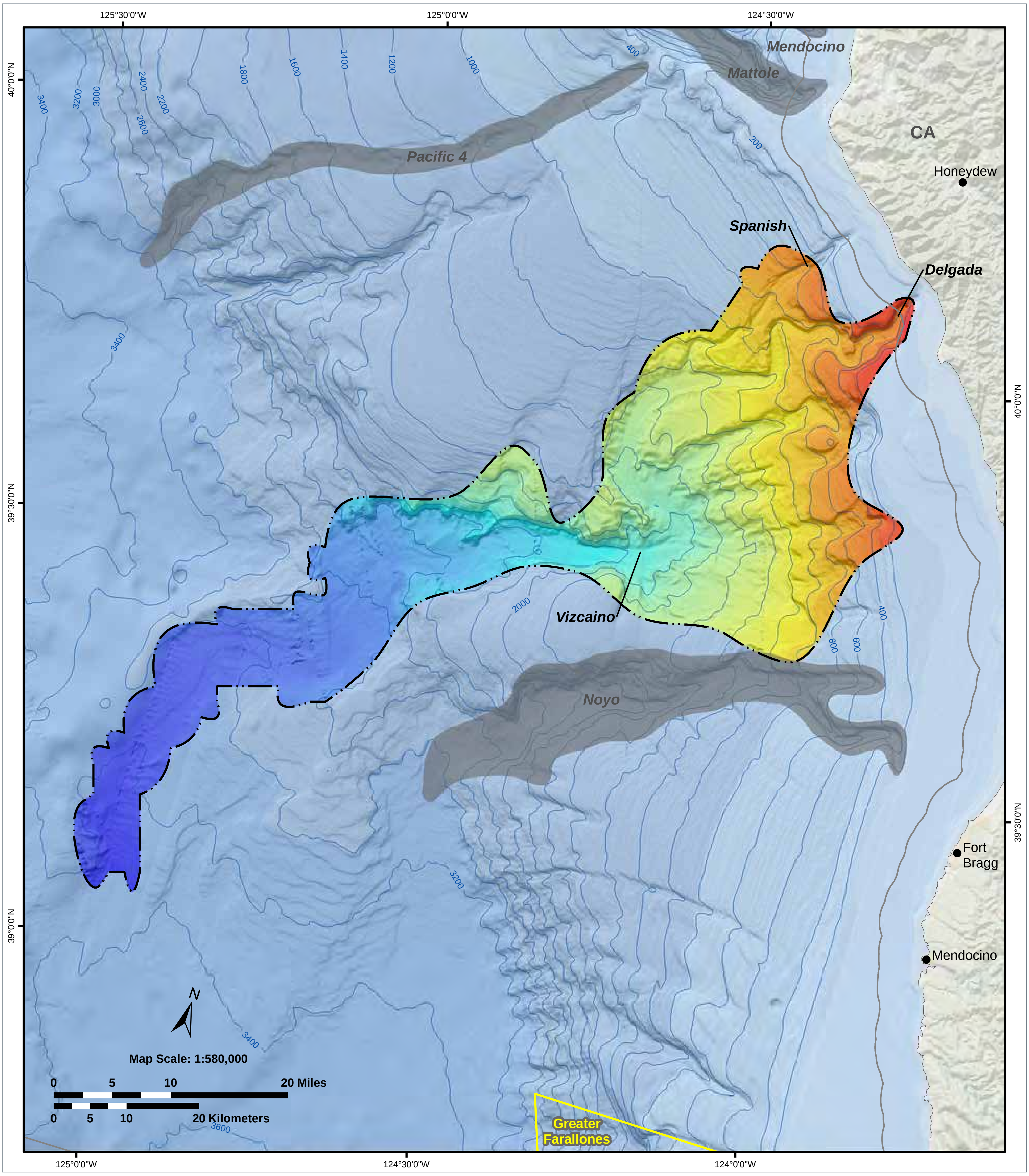
NOTABLE FACTS

Eel Slump, a feature within the canyon, is a landslide scar located 2.5 km southwest of the sharp bend in the canyon between 1,230 and 1,800 m water depth (Gwiazda et al. 2016). Most of the sediment feeding into Eel Canyon originates from storm-induced resuspension events on the adjacent shelf (Puig et al. 2003).

The Eel River is thought to have run directly into Eel Canyon until the end of the Pleistocene, when sea levels were lower; the two features are now separated by about 20 km of shallow marine shelf (Paull et al. 2014).

Patches of chemosynthetic clams were observed in this canyon, suggesting the presence of hydrogen sulfide in the sediment (von Thun 2013).

DELGADA CANYON SYSTEM



NOTABLE FACTS

Analysis of bathymetric surveys suggests that the Delgada Canyon mainstem is actively carved into bedrock by turbidity currents generated at the Delgada Canyon head wall (Smith et al. 2018).

Delgada Canyon is one of the tributary canyons to the Delgada Fan complex (Atwater 1970). It is possible that the coalescing canyon systems on the continental slope have remained with the fan and adjacent sea floor during the Neogene transform offset. Another possibility is that the two main lobes of the fan, which include the bulk of the upper-fan deposits, are relatively recent features. (Normark and Gutmacher 1985).

Sediment transport and accumulation at the Delgada Canyon head is controlled primarily by wave-induced shear stress influenced by the regional longshore current (Smith et al. 2018).

Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

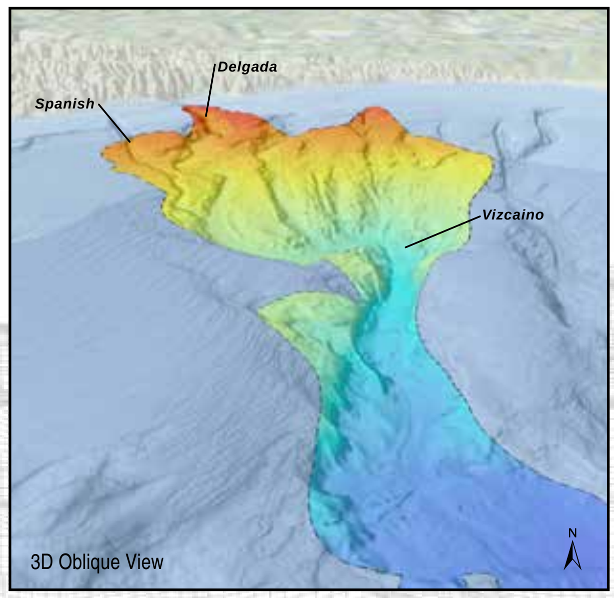
Submarine Canyon Bathymetry

60 1700 3340

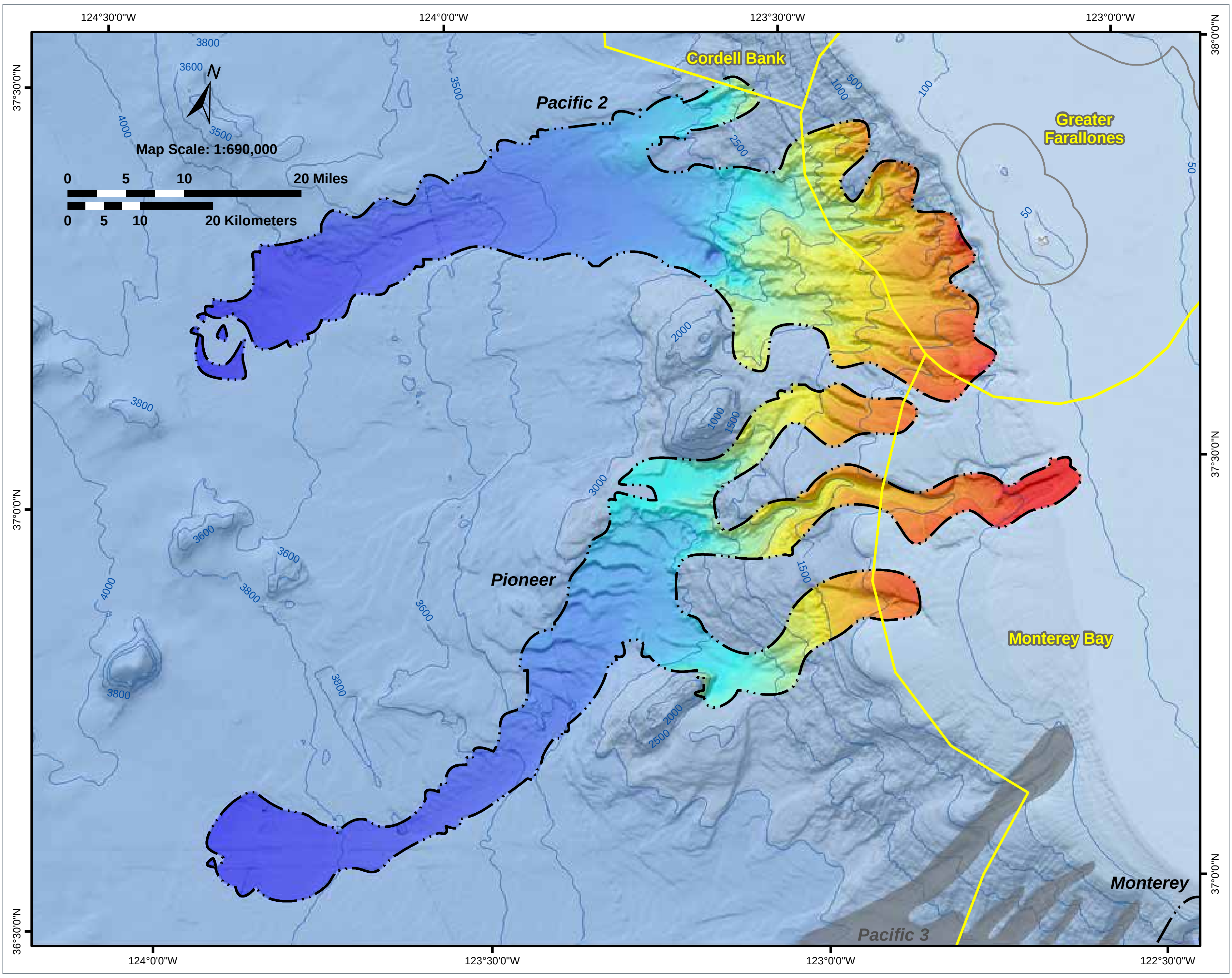
Depth in meters

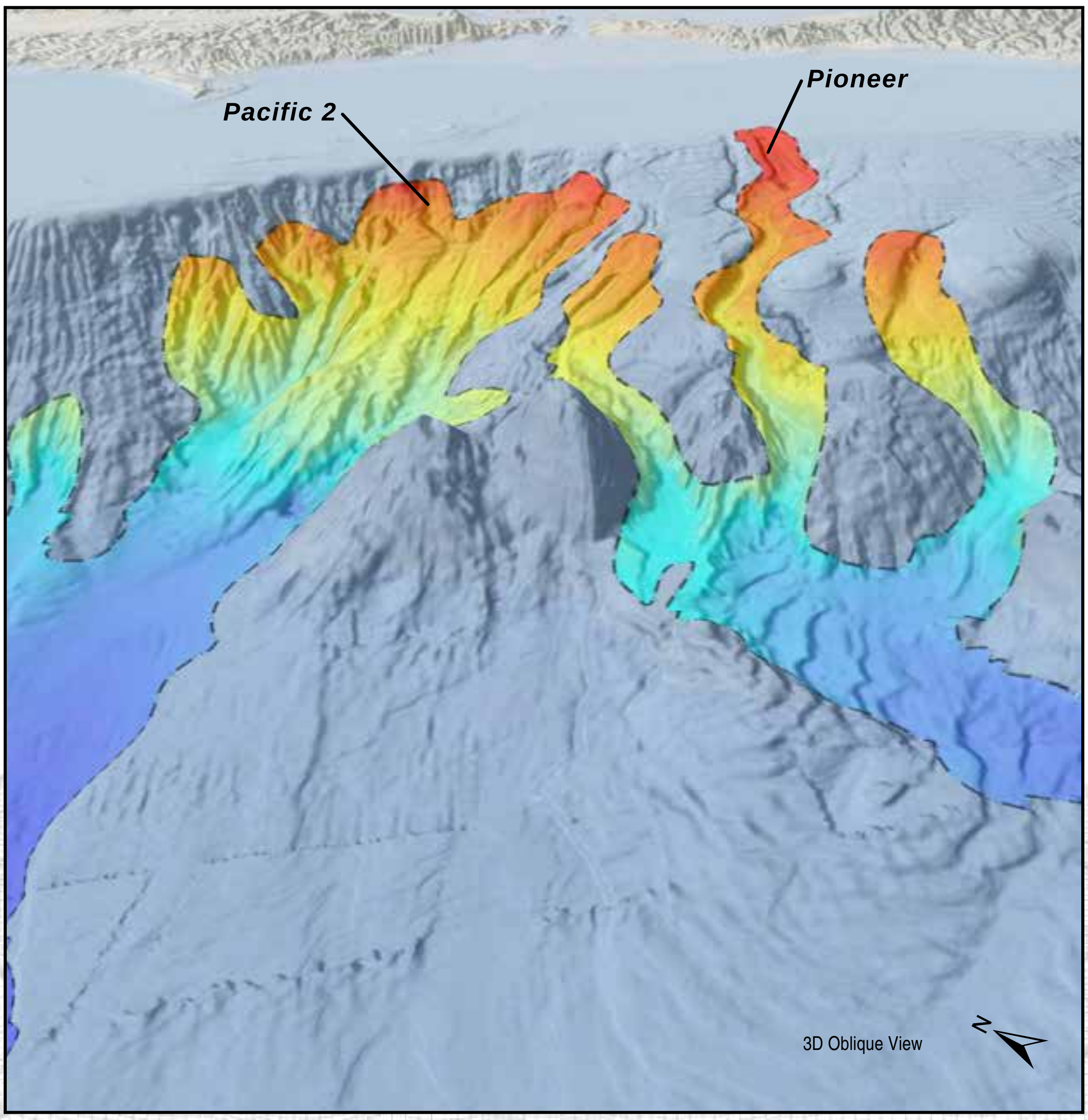
Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management



PACIFIC 2 AND PIONEER CANYON





Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

110 2040 3960

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

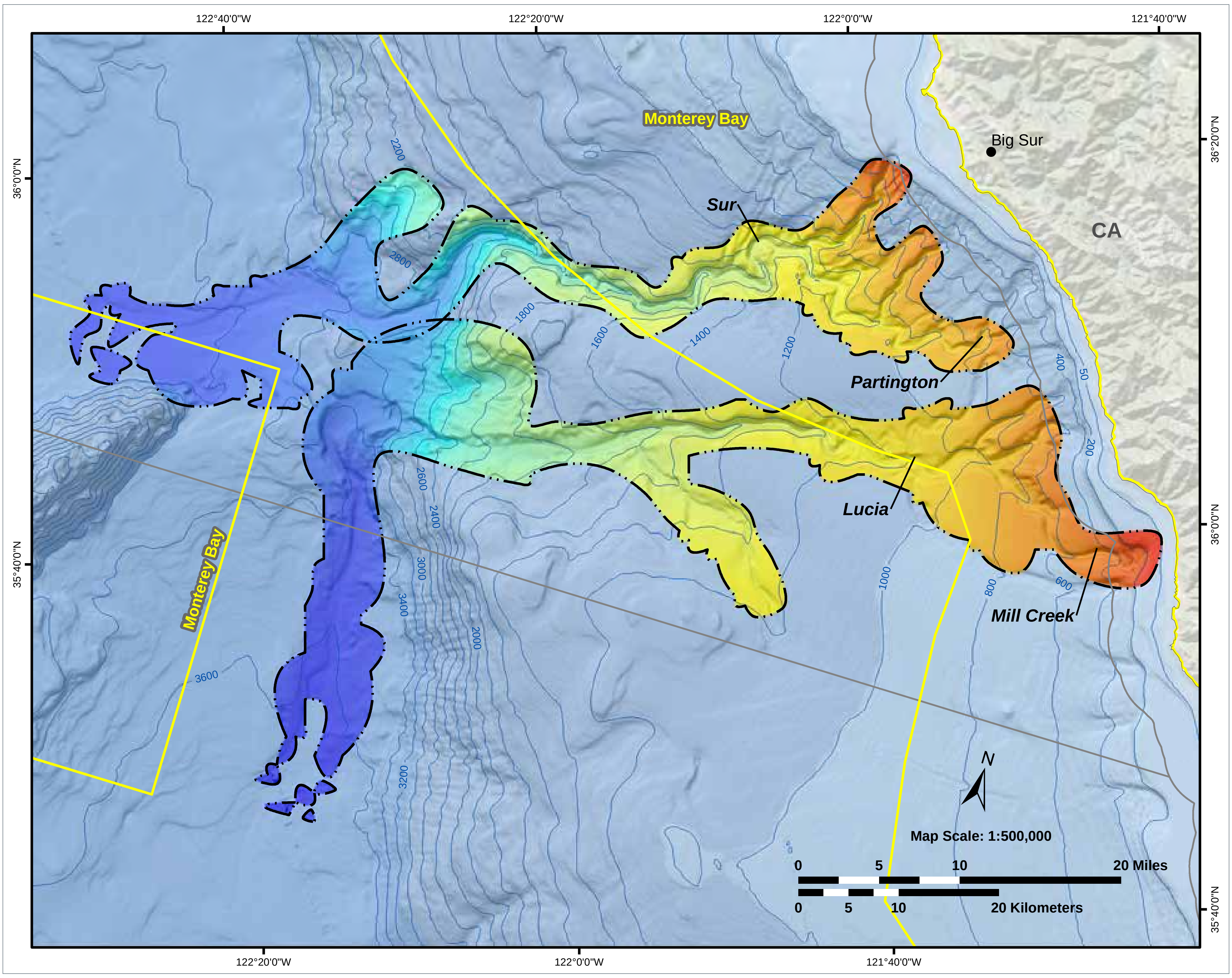
NOTABLE FACTS

The head regions of the Pacific 2 Canyon begin within three different National Marine Sanctuaries (NMSs): Greater Farallones NMS, Cordell Bank NMS, and Monterey Bay NMS.

Pioneer Canyon originally developed as the seaward channel of Monterey Canyon and was displaced northward to its present locations by right lateral faulting (Howell et al. 1980).

Black-footed albatross have been reported to concentrate in great numbers at the head of Pioneer Canyon (Santora et al. 2012). In 2016, an expedition of Pioneer Canyon discovered many bamboo coral forests and rocky features with multiple coral species, sponges, invertebrates, and fish (Roletto et al. 2016).

SUR AND LUCIA CANYON SYSTEMS



Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

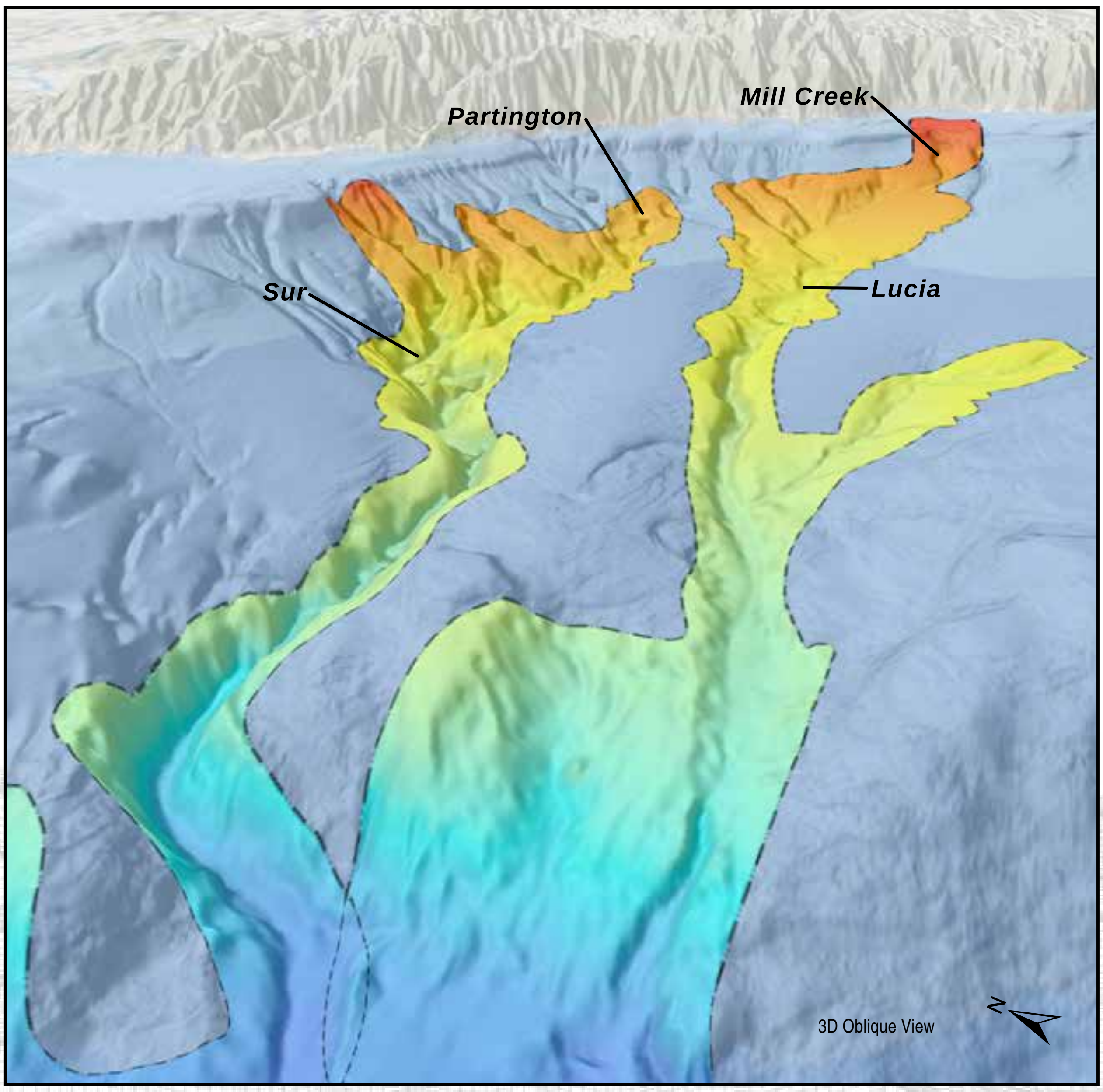
Submarine Canyon Bathymetry

40 | 1910 | 3770

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management



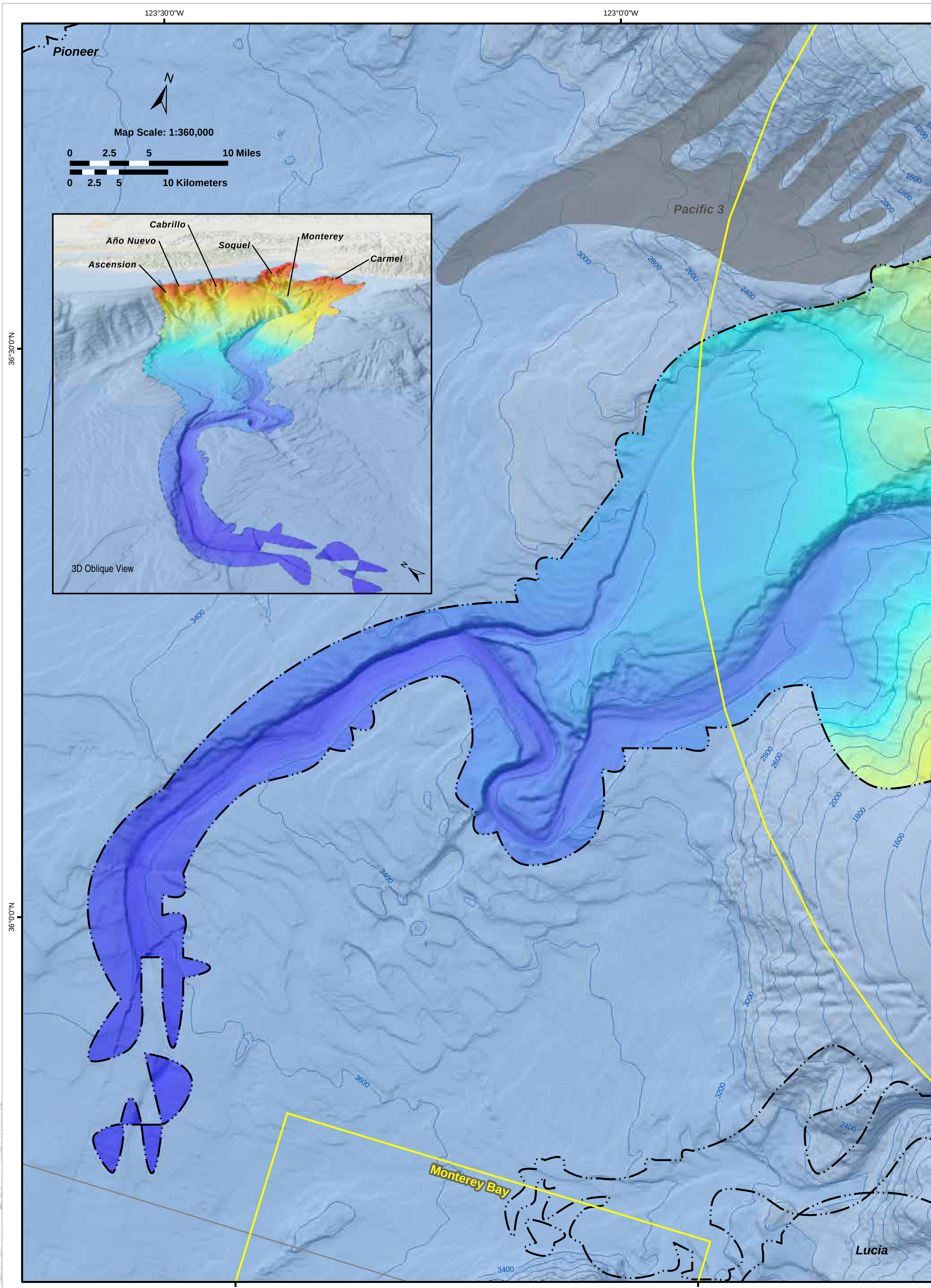
NOTABLE FACTS

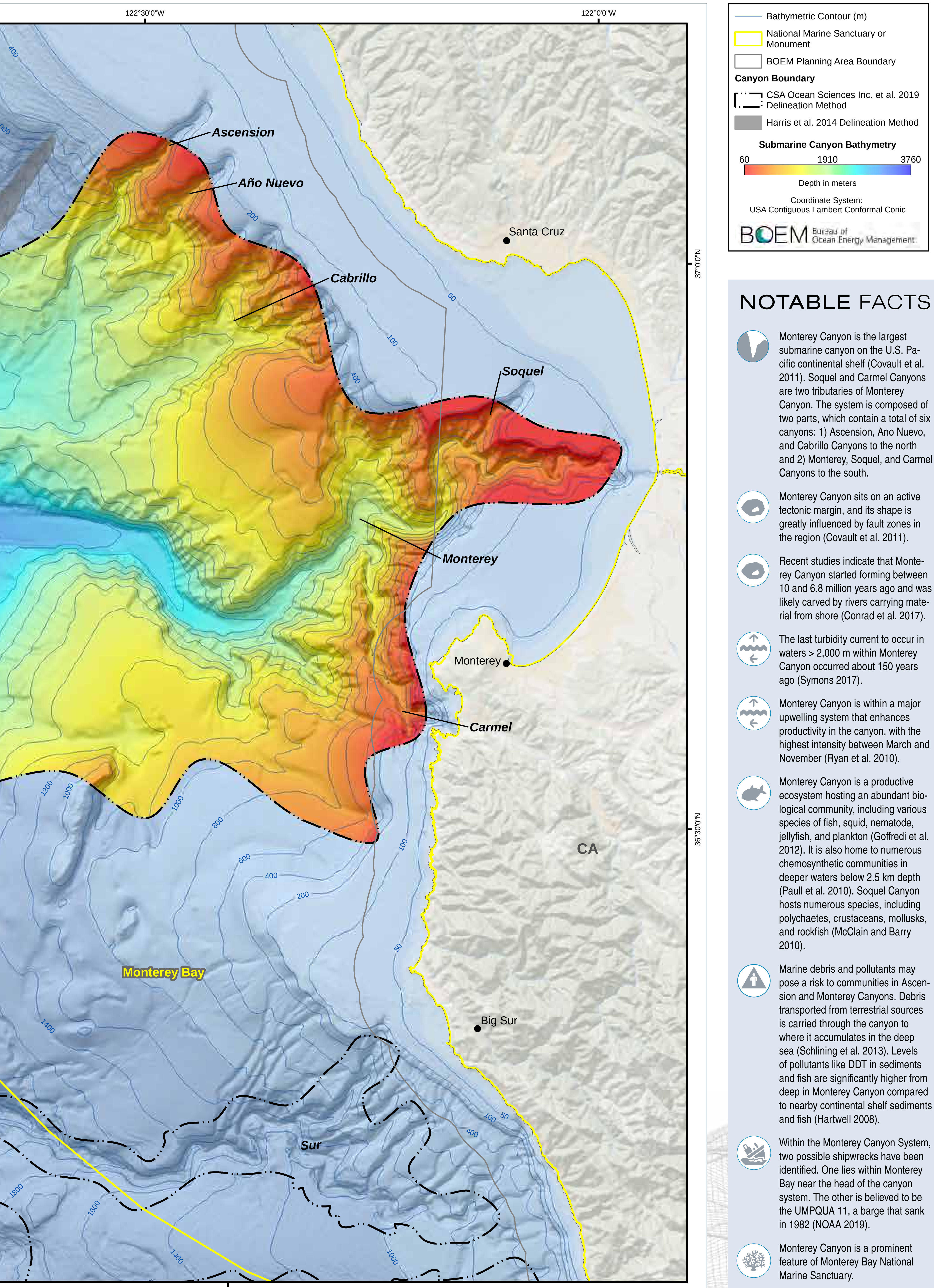
Partington Canyon is a major tributary branch of Sur Canyon (Harris et al. 2014). The Sur Canyon system is intersected on the upper slope by a segment of the San Gregorio Fault Zone (part of the San Andreas Fault System), which has rates of lateral motion of around 6 to 9 mm/yr (Harris et al. 2014).

In a 2003 survey, the Sanctuary Integrated Monitoring Network reported that 48 species of fish were observed in Partington Canyon, including 27 species of rockfish (SIMoN n.d.).

The head of the Lucia Canyon system acts as a funnel for the rapid transport of detritus eroded from the Santa Lucia Mountains to the deep abyssal plain (SIMoN n.d.).

MONTEREY CANYON SYSTEM





NOTABLE FACTS

Monterey Canyon is the largest submarine canyon on the U.S. Pacific continental shelf (Covault et al. 2011). Soquel and Carmel Canyons are two tributaries of Monterey Canyon. The system is composed of two parts, which contain a total of six canyons: 1) Ascension, Ano Nuevo, and Cabrillo Canyons to the north and 2) Monterey, Soquel, and Carmel Canyons to the south.

Monterey Canyon sits on an active tectonic margin, and its shape is greatly influenced by fault zones in the region (Covault et al. 2011).

Recent studies indicate that Monterey Canyon started forming between 10 and 6.8 million years ago and was likely carved by rivers carrying material from shore (Conrad et al. 2017).

The last turbidity current to occur in waters > 2,000 m within Monterey Canyon occurred about 150 years ago (Symons 2017).

Monterey Canyon is within a major upwelling system that enhances productivity in the canyon, with the highest intensity between March and November (Ryan et al. 2010).

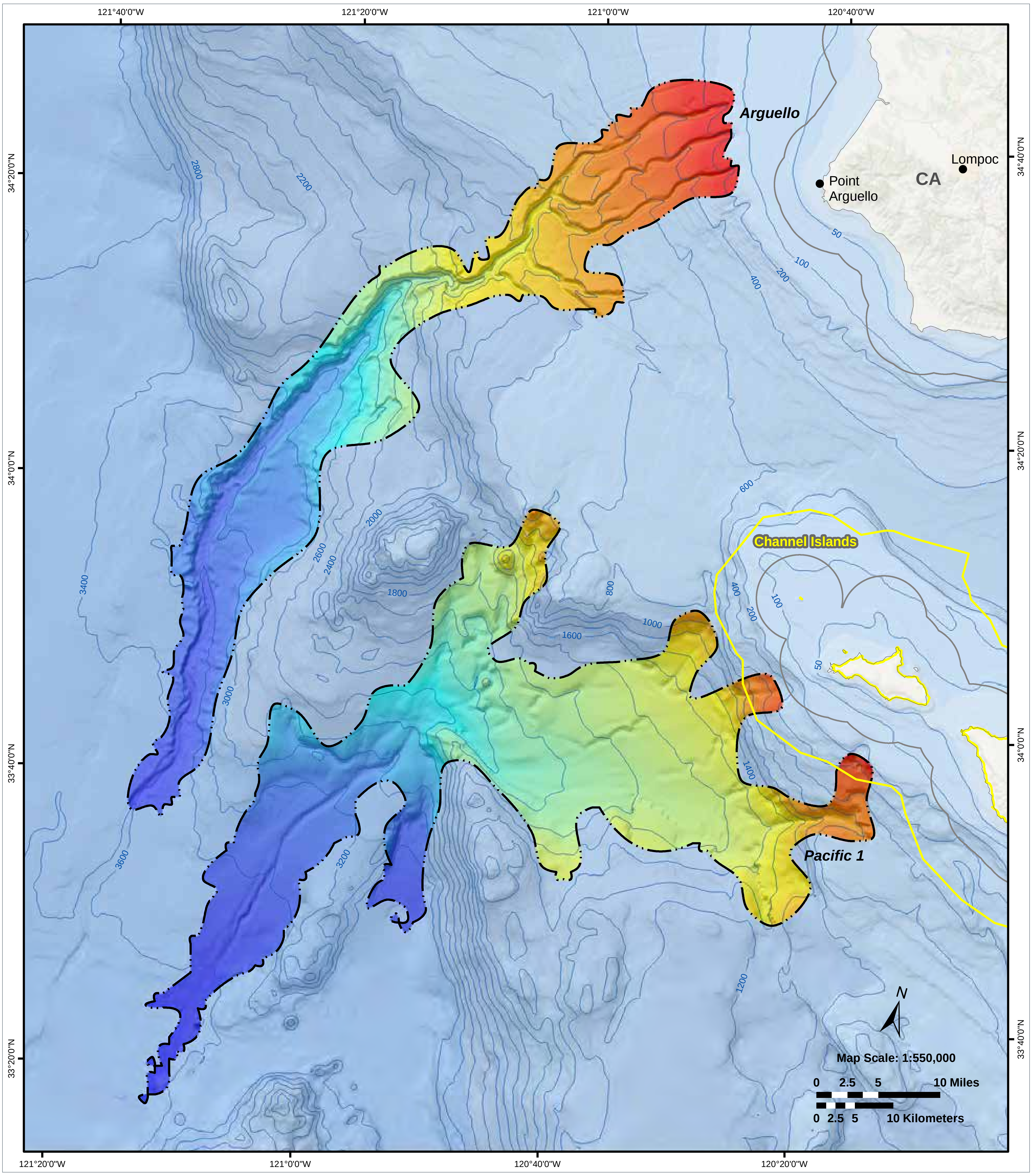
Monterey Canyon is a productive ecosystem hosting an abundant biological community, including various species of fish, squid, nematode, jellyfish, and plankton (Goffredi et al. 2012). It is also home to numerous chemosynthetic communities in deeper waters below 2.5 km depth (Paull et al. 2010). Soquel Canyon hosts numerous species, including polychaetes, crustaceans, mollusks, and rockfish (McClain and Barry 2010).

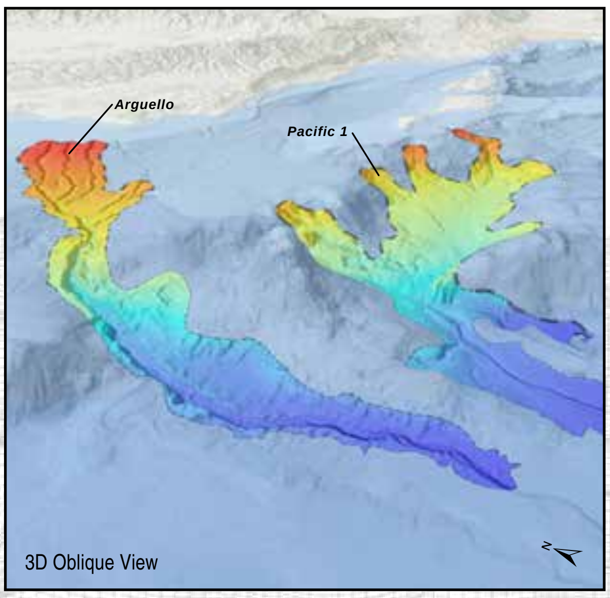
Marine debris and pollutants may pose a risk to communities in Ascension and Monterey Canyons. Debris transported from terrestrial sources is carried through the canyon to where it accumulates in the deep sea (Schlining et al. 2013). Levels of pollutants like DDT in sediments and fish are significantly higher from deep in Monterey Canyon compared to nearby continental shelf sediments and fish (Hartwell 2008).

Within the Monterey Canyon System, two possible shipwrecks have been identified. One lies within Monterey Bay near the head of the canyon system. The other is believed to be the UMPQUA 11, a barge that sank in 1982 (NOAA 2019).

Monterey Canyon is a prominent feature of Monterey Bay National Marine Sanctuary.

ARGUELLO AND PACIFIC 1 CANYONS





Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

110 1920 3730

Depth in meters

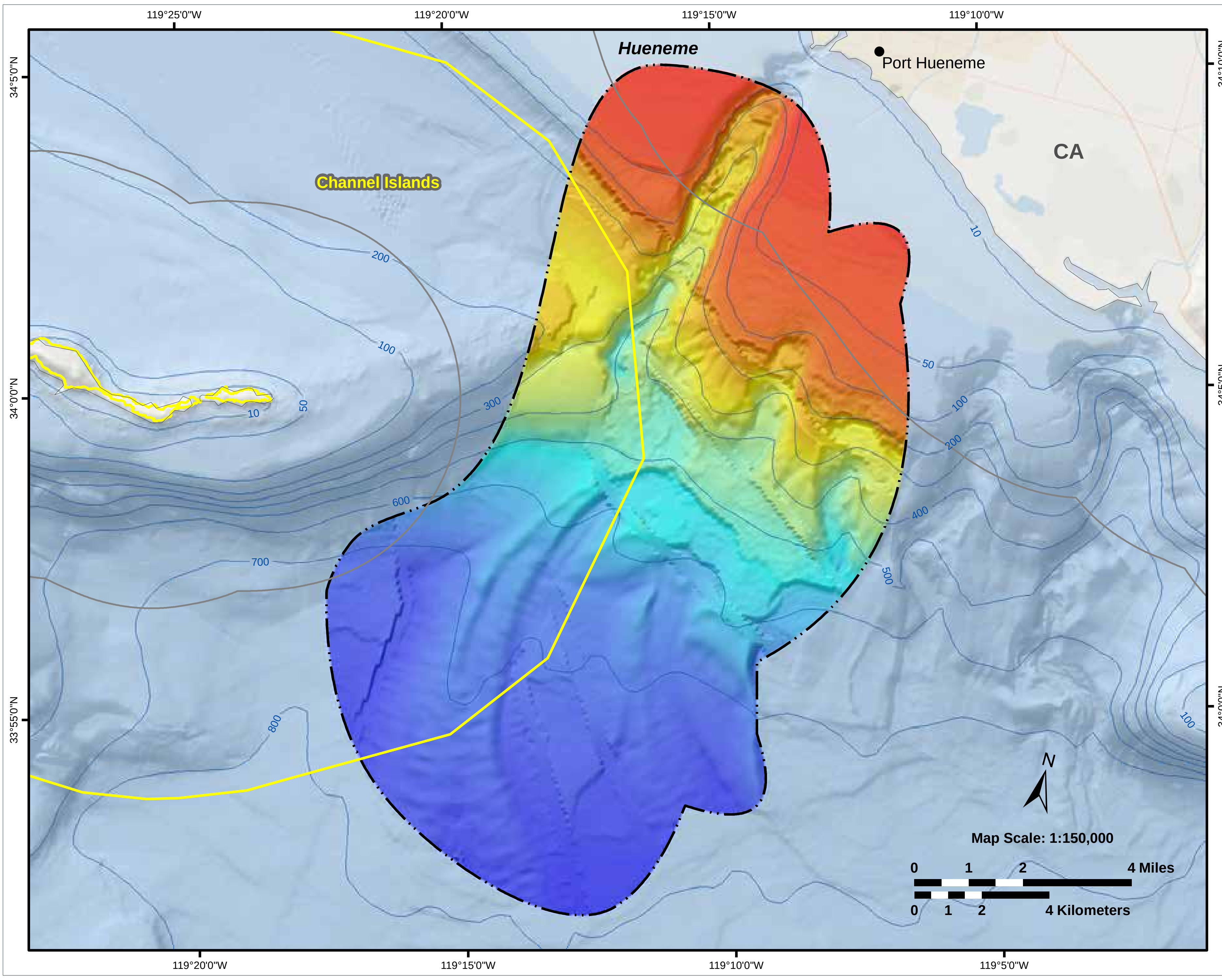
Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

- Seasonal north and south current movement deposits sediment that is then carried seaward via the Arguello Canyon to the Arguello fan (Wilde 1965).
- On a *Nautilus* expedition in 2016, researchers found deep sea corals, octopus, and a potentially new species of sea slug in Arguello Canyon (NOAA 2016).
- Pacific 1 Canyon is west of San Miguel and Santa Rosa Islands.
- Pacific 1 Canyon reaches into Channel Islands National Marine Sanctuary.

HUENEME CANYON



Bathymetric Contour (m)

National Marine Sanctuary or Monument

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

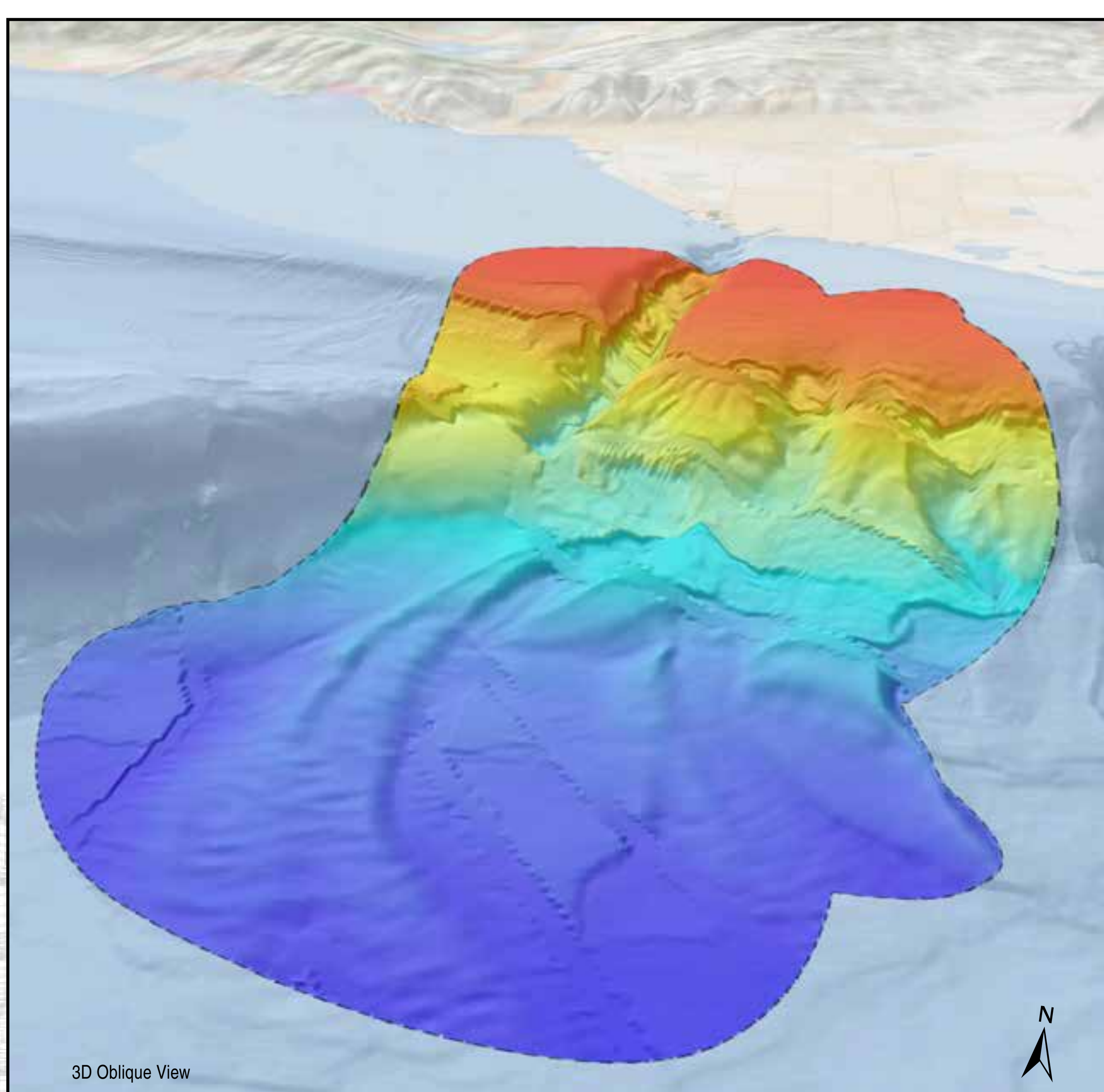
Submarine Canyon Bathymetry

30 410 780

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management



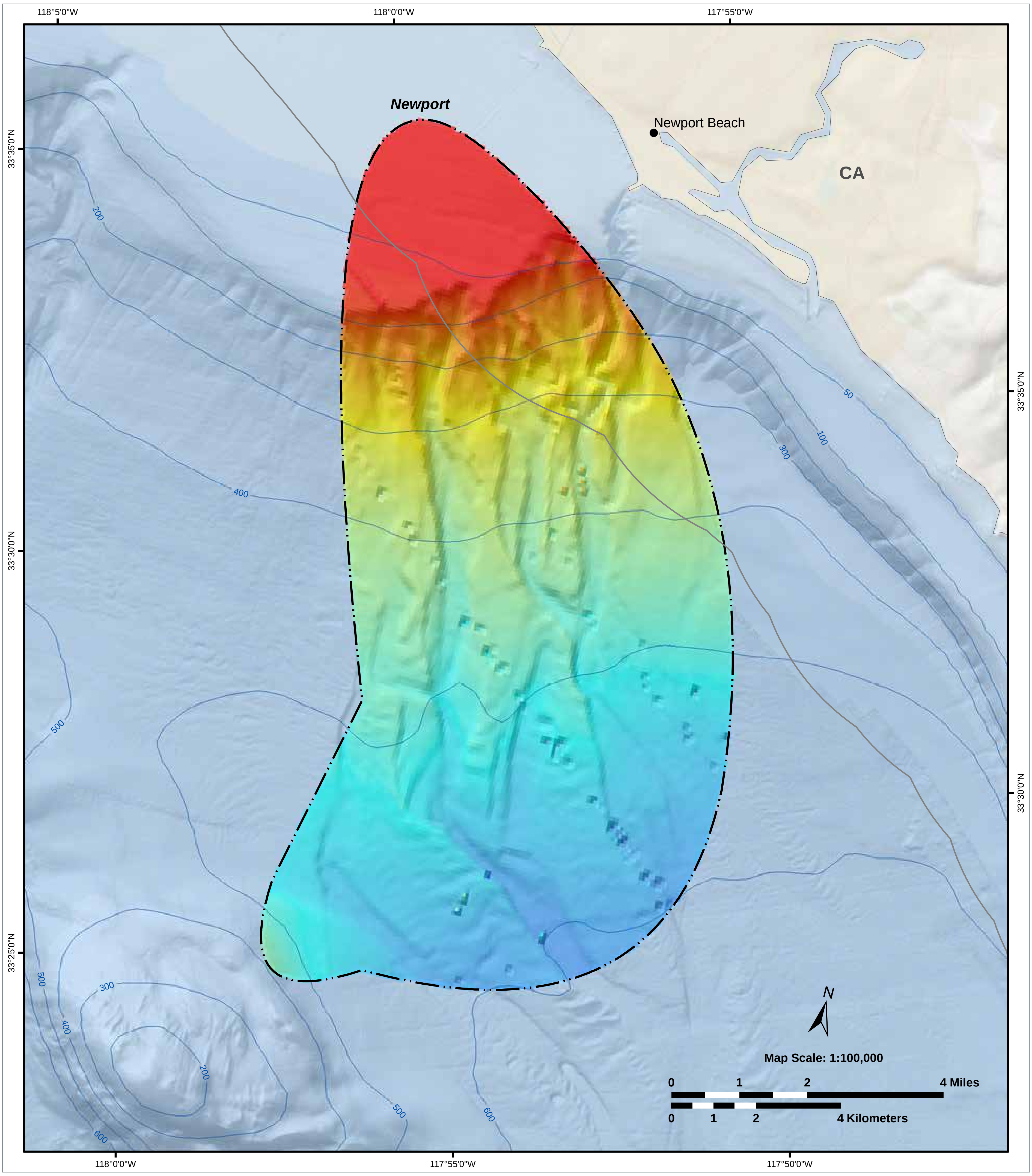
NOTABLE FACTS

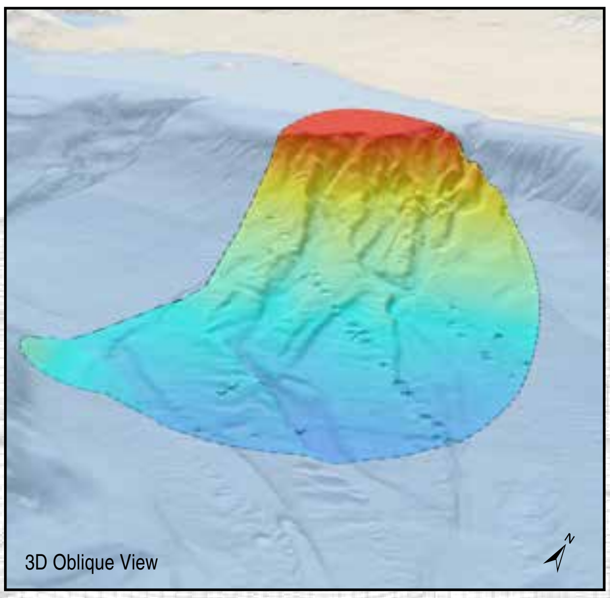
This canyon was formed by turbidity currents beginning approximately 15,000 years ago (Romans 2011). In modern day, the canyon rim morphology coupled with storm-induced sediment resuspension on the shelf are the major controls of sediment fluxes into the canyon (Xu et al. 2010). The canyon is still active today, receiving huge volumes of sand from the northwest-to-southeast longshore transport of beach sand.

Because the head of this canyon is accessible from the shoreline, it is a popular spot for recreational diving.

In 2003, a 24-m wood hull fishing vessel sank in this canyon (NOAA 2019).

NEWPORT CANYON





Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

20 320 610

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management

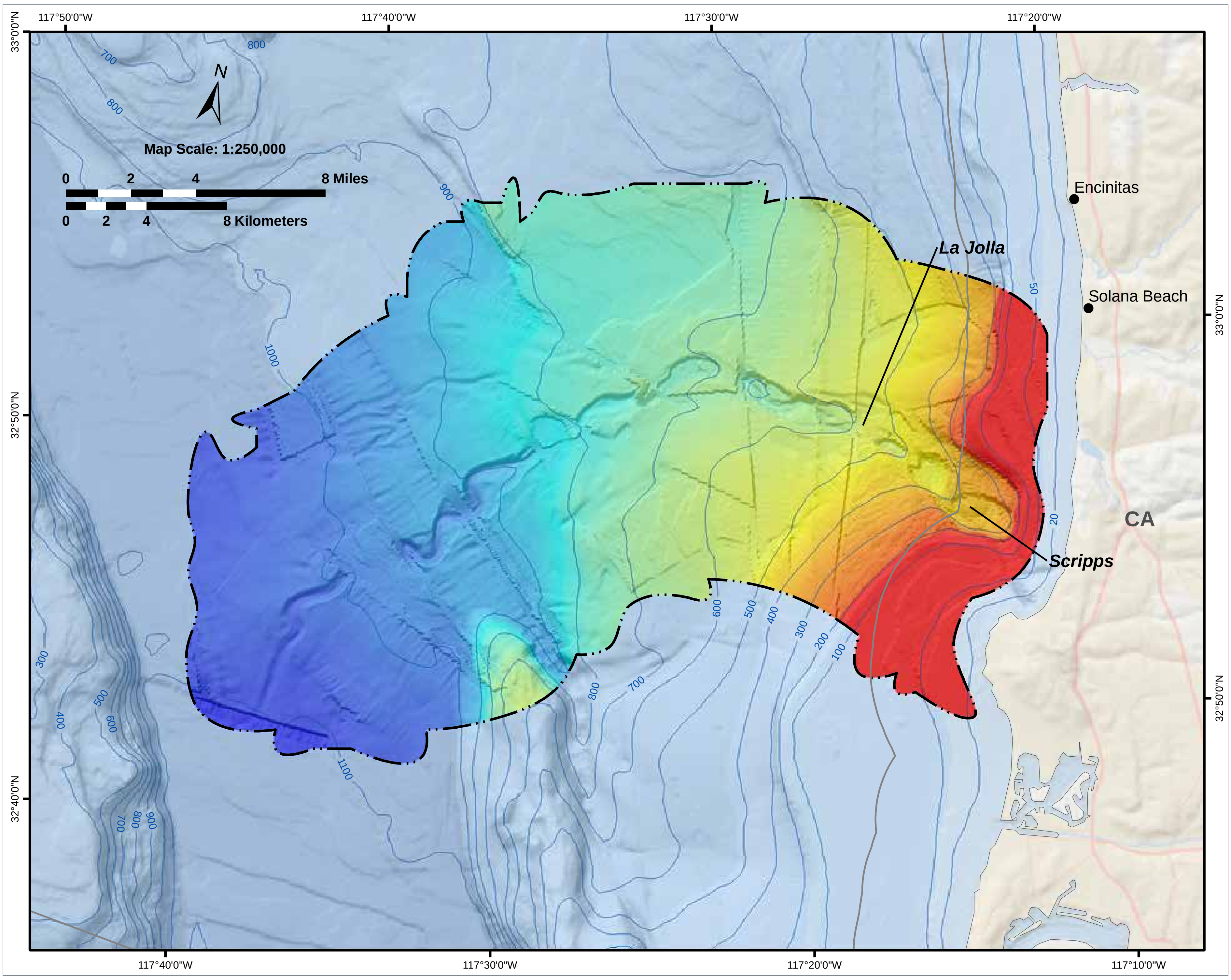
NOTABLE FACTS

Newport Canyon was formed at a point where the shelf is narrow, and the sand was moved by waves in longshore drift and concentrated at a convergence zone near the canyon head (Felix and Gorsline 1971).

The benthic biodiversity in this canyon has been reported to be higher than in other Southern California canyons. This has been attributed to calmer conditions in terms of bottom current dynamics (i.e., less physical disturbance affecting the surface sediments at the axis of the canyon [Maurer et al. 1995]).

Similar to Hueneme Canyon, the head of this canyon is accessible from the shoreline and is a popular spot for recreational diving.

LA JOLLA / SCRIPPS CANYON SYSTEM



Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

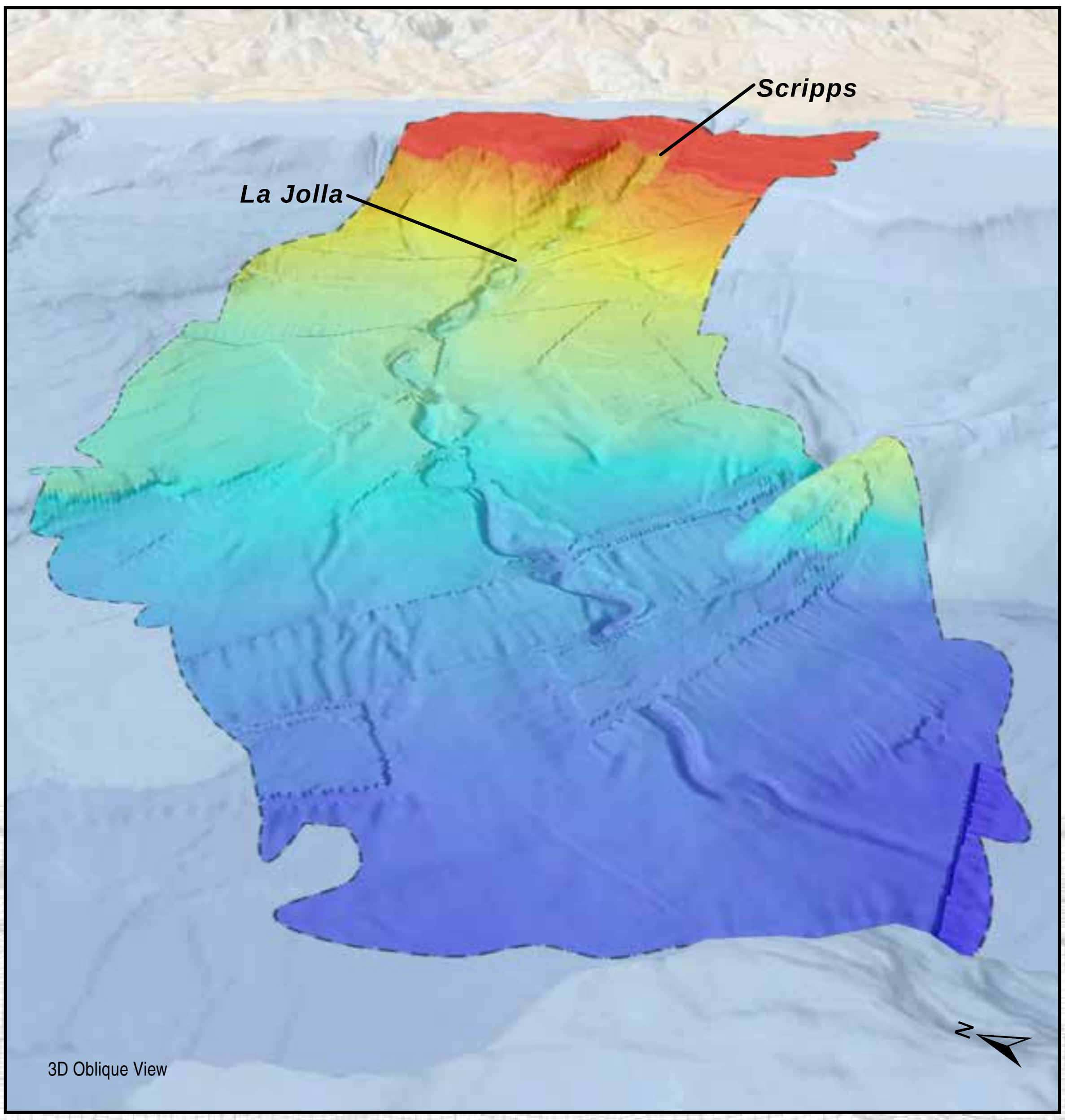
Submarine Canyon Bathymetry

20 600 1170

Depth in meters

Coordinate System:
USA Contiguous Lambert Conformal Conic

BOEM Bureau of Ocean Energy Management



3D Oblique View

NOTABLE FACTS

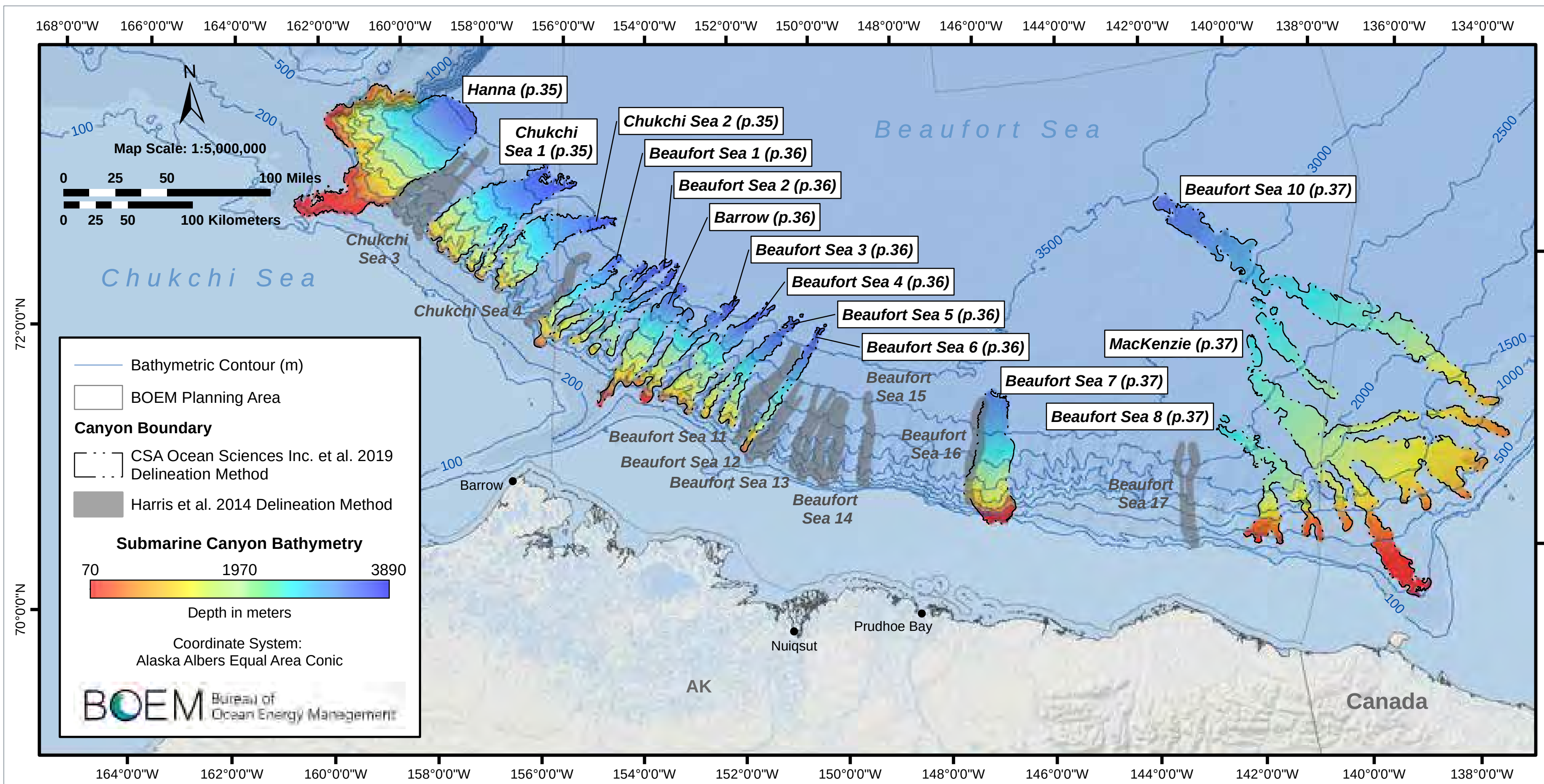
Data from the La Jolla Canyon walls indicate that it is less than 1.2 million years old. There is evidence that a lagoon once existed at the head of the canyon, based on photographs in the early 1900s and a 10-m thick deposit of estuarine material throughout the head (Paull et al. 2013).

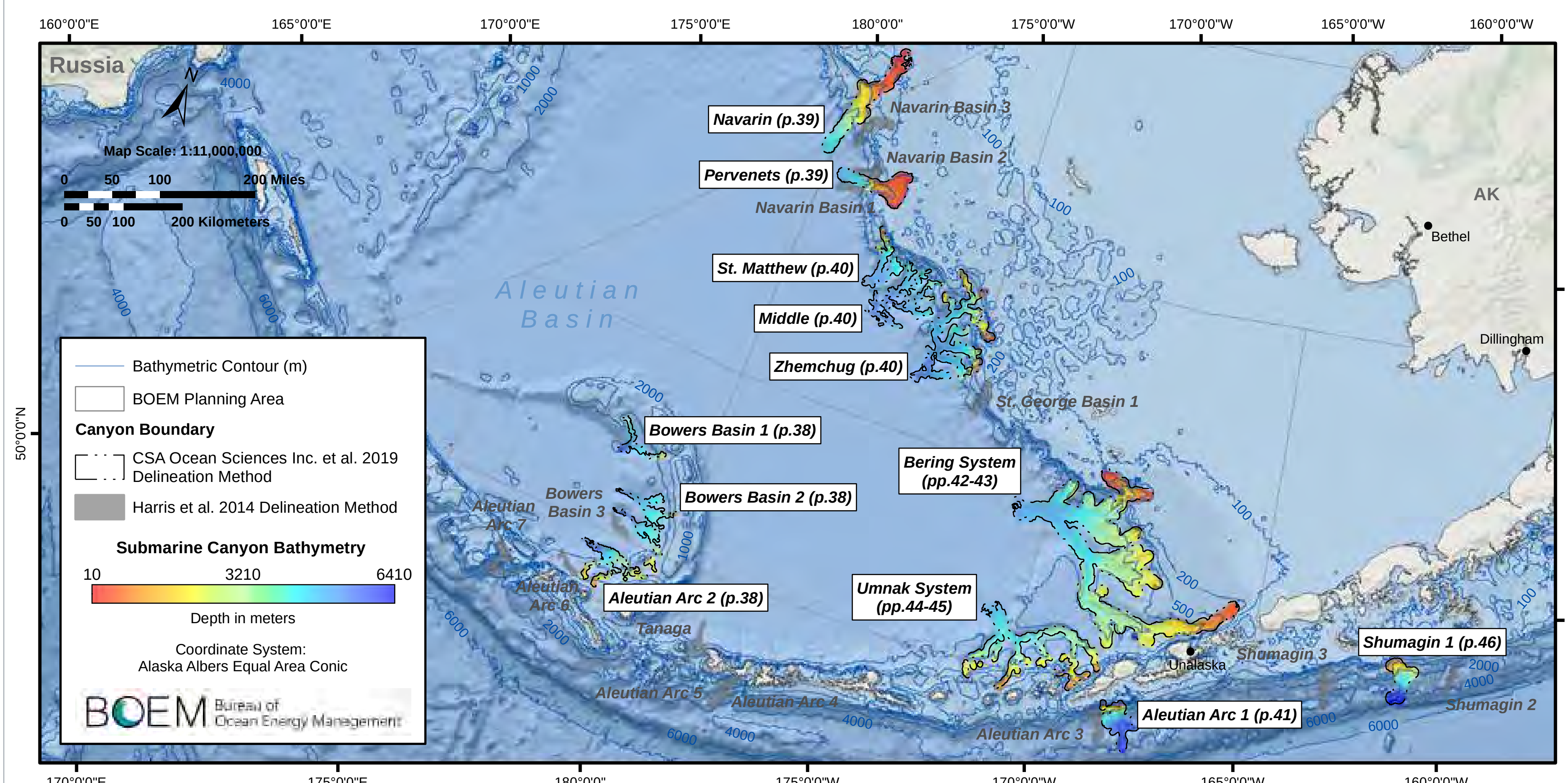
The heads of the La Jolla Canyon system extend into shallow water, which modifies nearshore circulation, surface wave patterns, and sediment transport (Le Dantec et al. 2010).

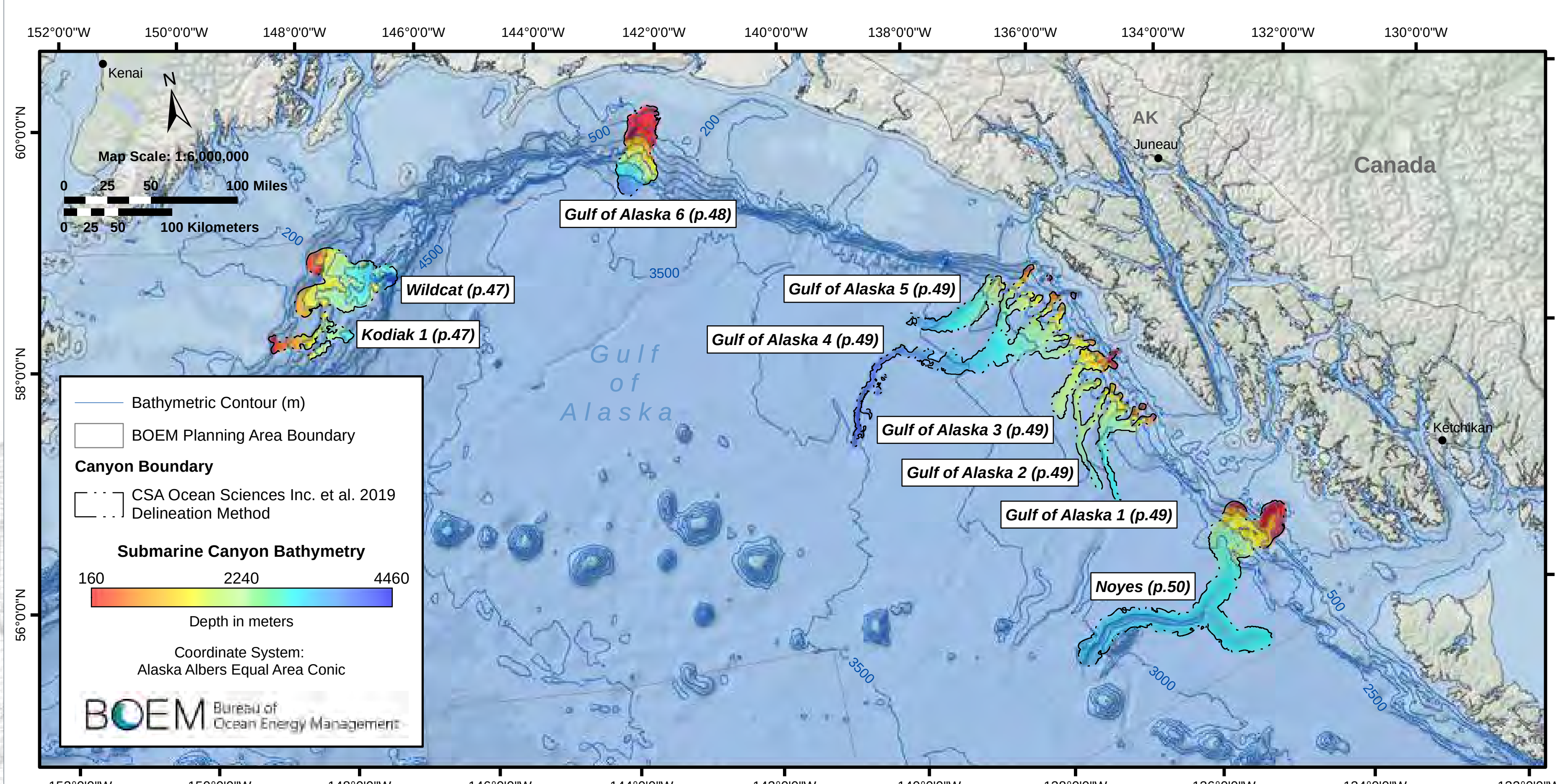
Abundance and diversity of benthic macrofauna and megafauna are higher in the Scripps Canyon compared to the adjacent slope (Vetter and Dayton 1998, 1999).

Ecological reserves have been designated around the head of the canyon, as it is a known spawning ground for market squid, potential nursery habitat for juvenile giant sea bass, and prime location for aggregations of leopard sharks (Nosal et al. 2013).

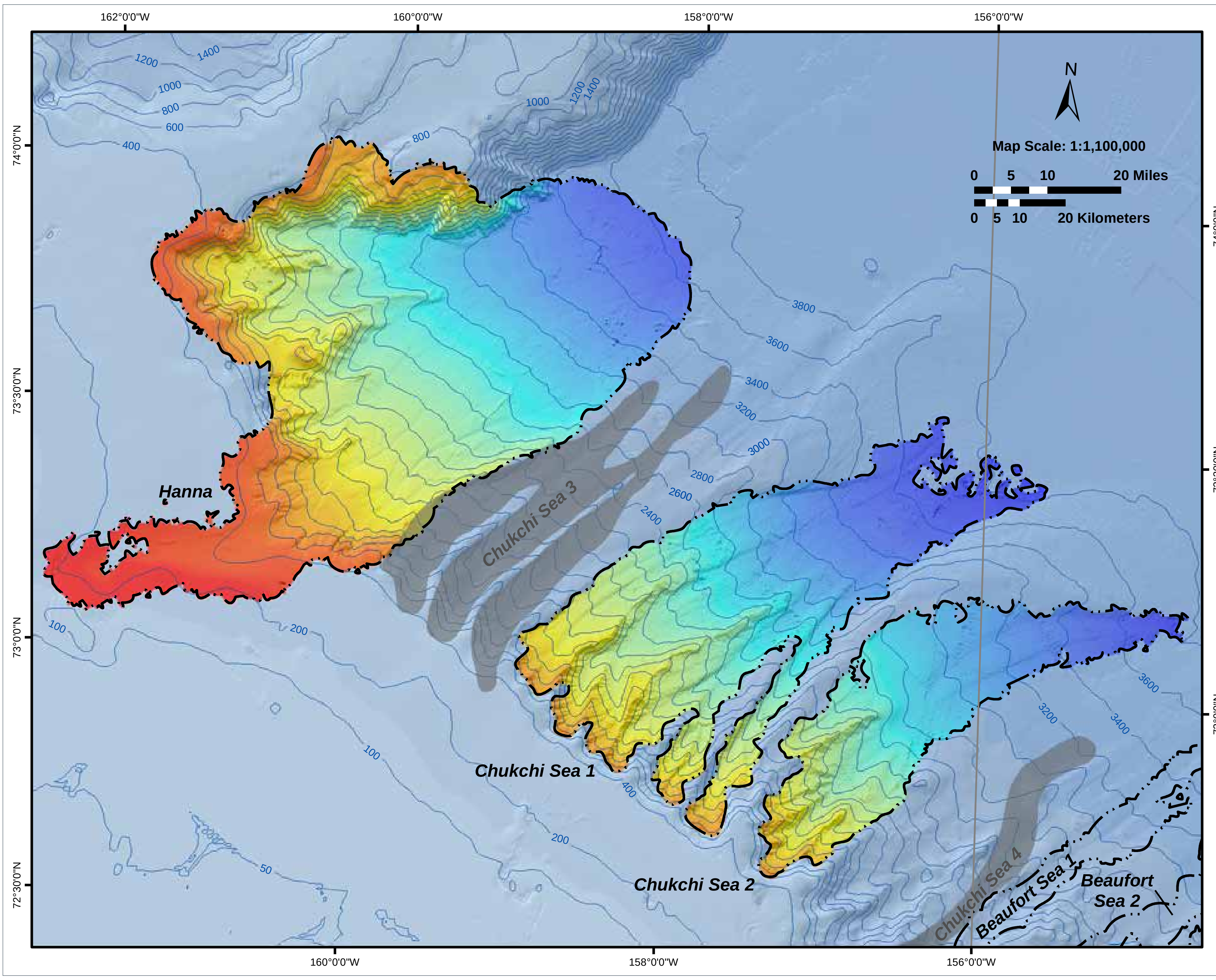
ALASKA CANYONS OVERVIEW







HANNA, CHUKCHI SEA 1, AND CHUKCHI SEA 2 CANYONS



Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

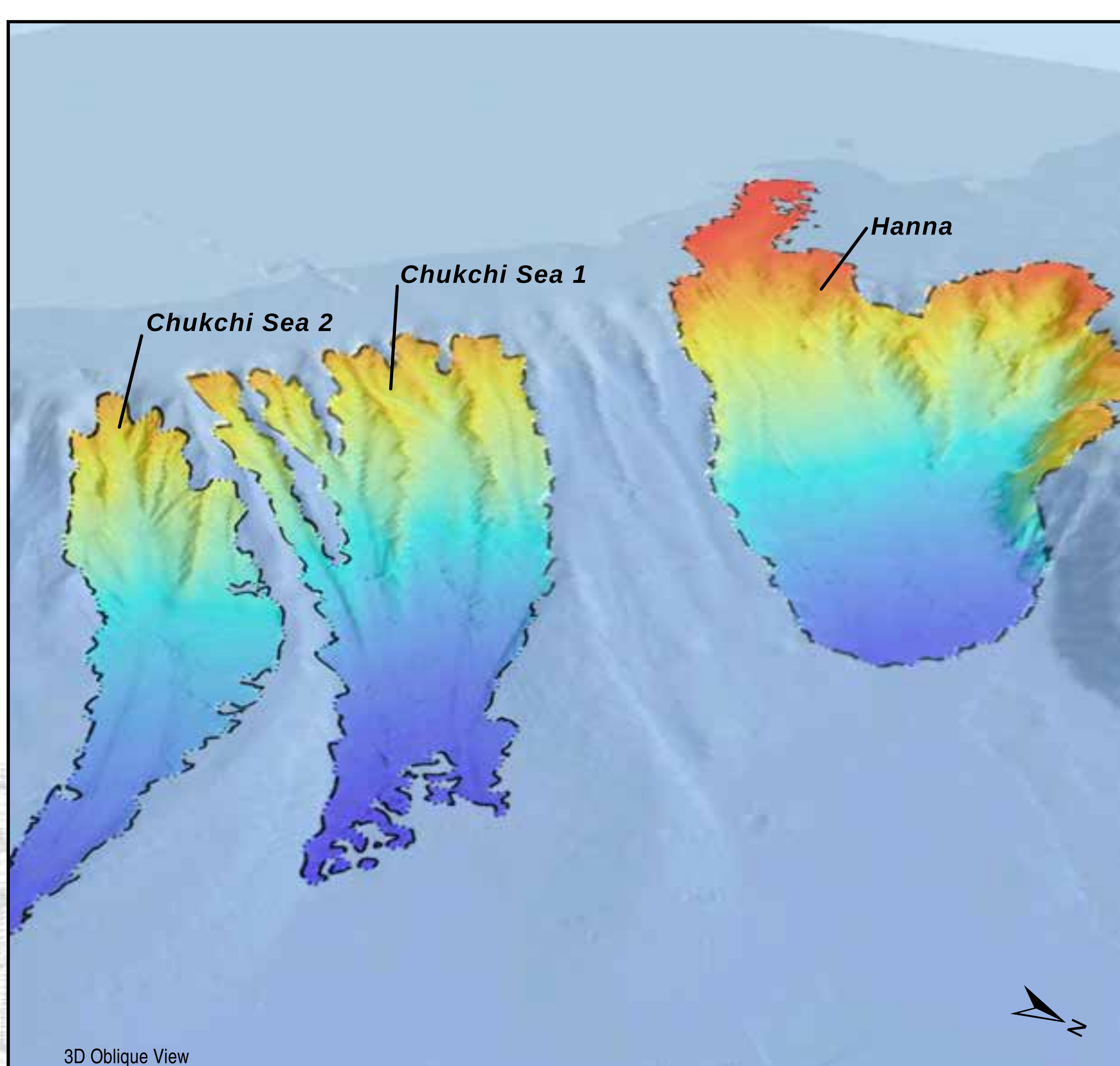
Submarine Canyon Bathymetry

100 2000 3900

Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management



3D Oblique View

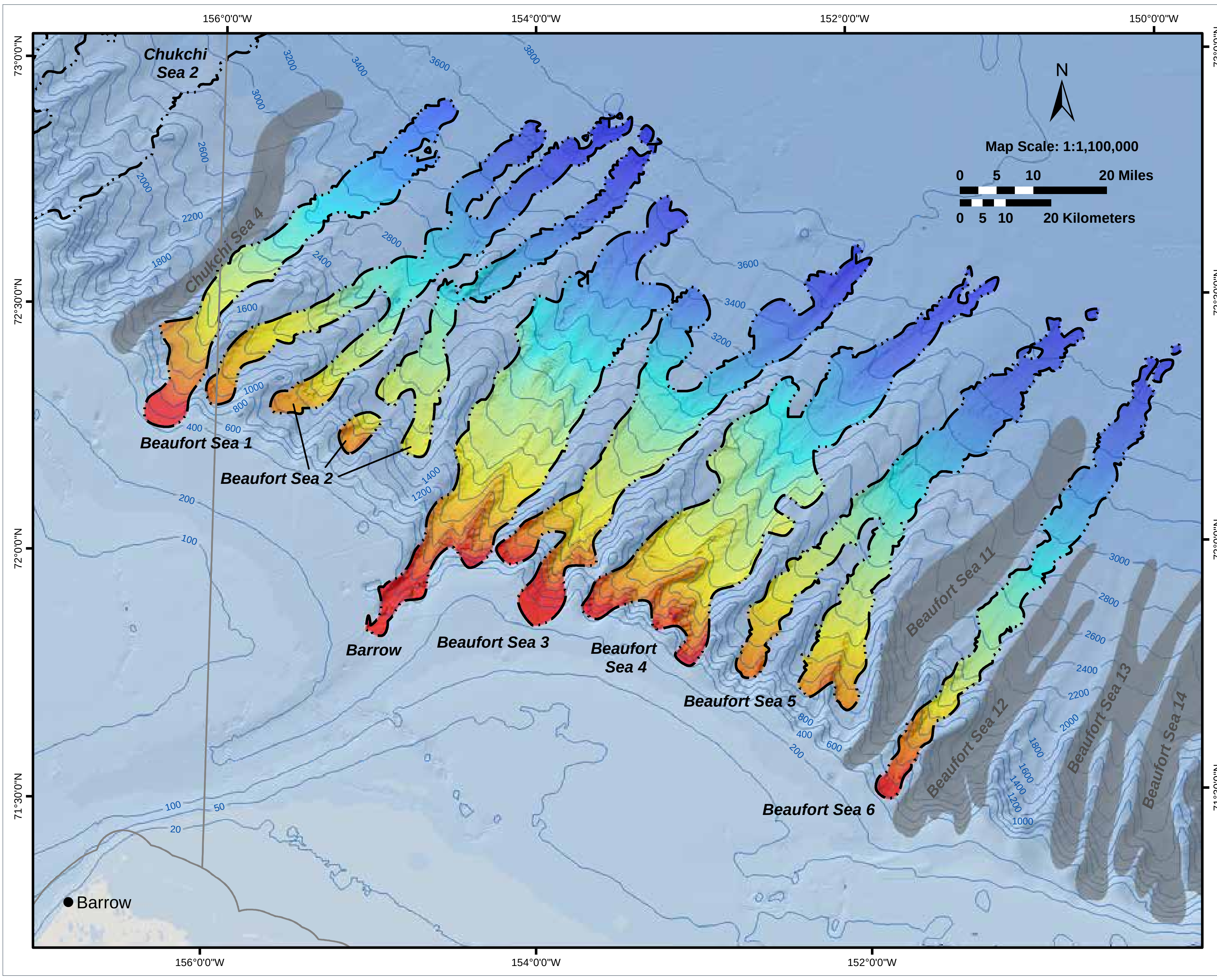
NOTABLE FACTS

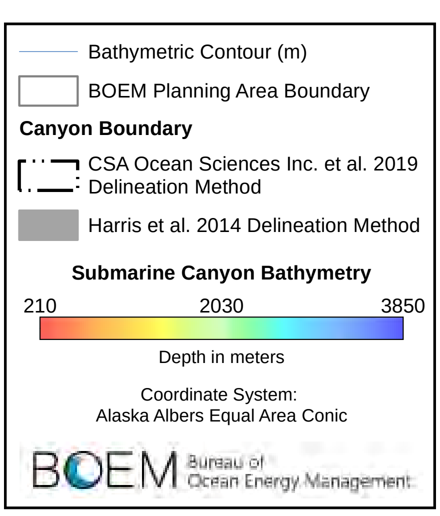
Hanna Canyon may be an abandoned late Pleistocene course of the Hope-Herald Sea Valley system (Grantz and Eittreim 1979).

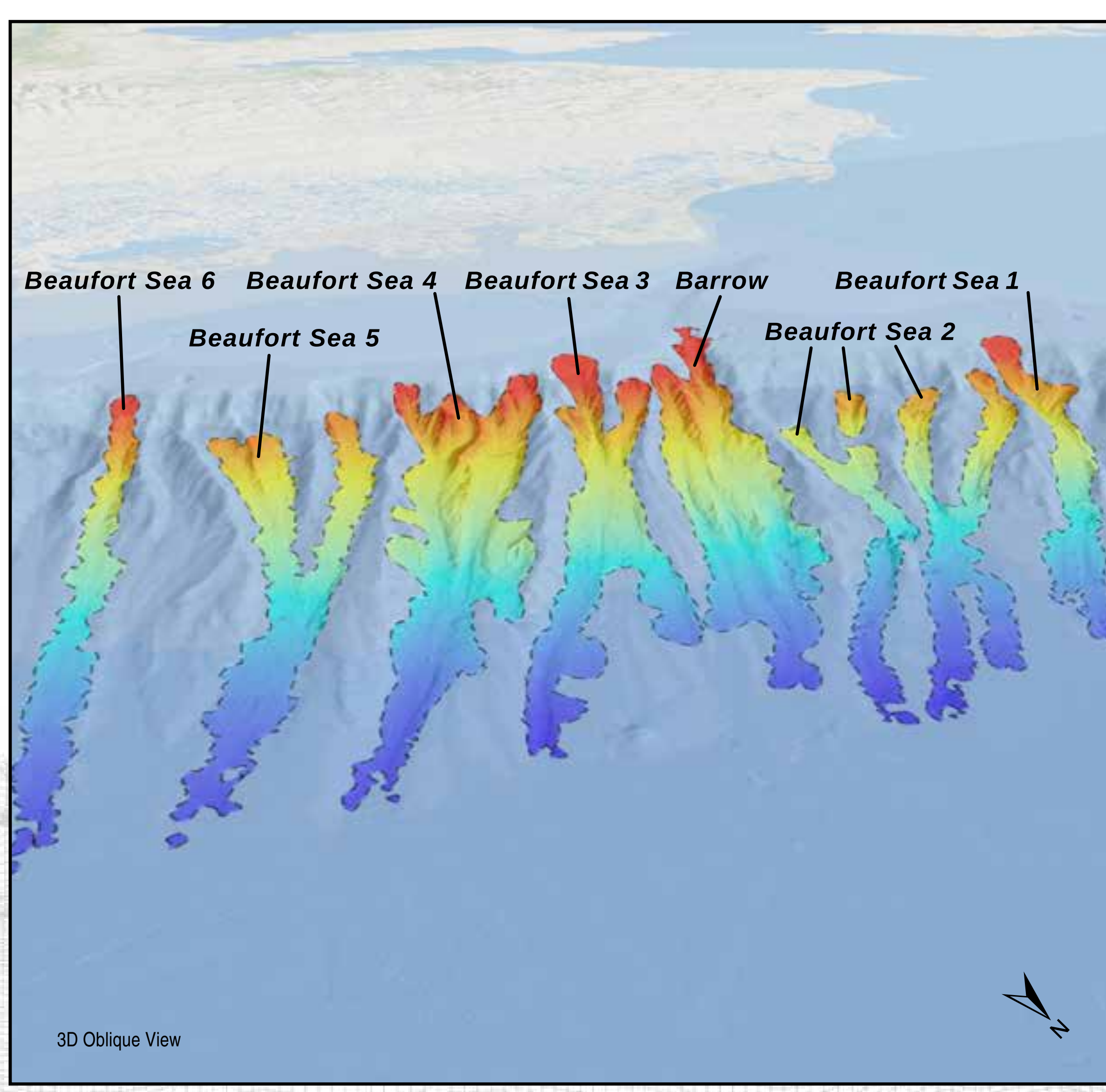
Circulation through the Chukchi Sea canyons may include subsurface Atlantic water, which flows from the northeast as upwelling to the continental shelf, and possibly circulation from the Central Channel, which flows from the Bering Sea (Day et al. 2013).

Hanna Canyon is positioned on the shelf edge north of Hanna Shoal, which is a shallow feature on the continental shelf and recognized as one of the Chukchi Sea's most productive areas (Day et al. 2013).

BARROW AND BEAUFORT SEA CANYONS 1-6





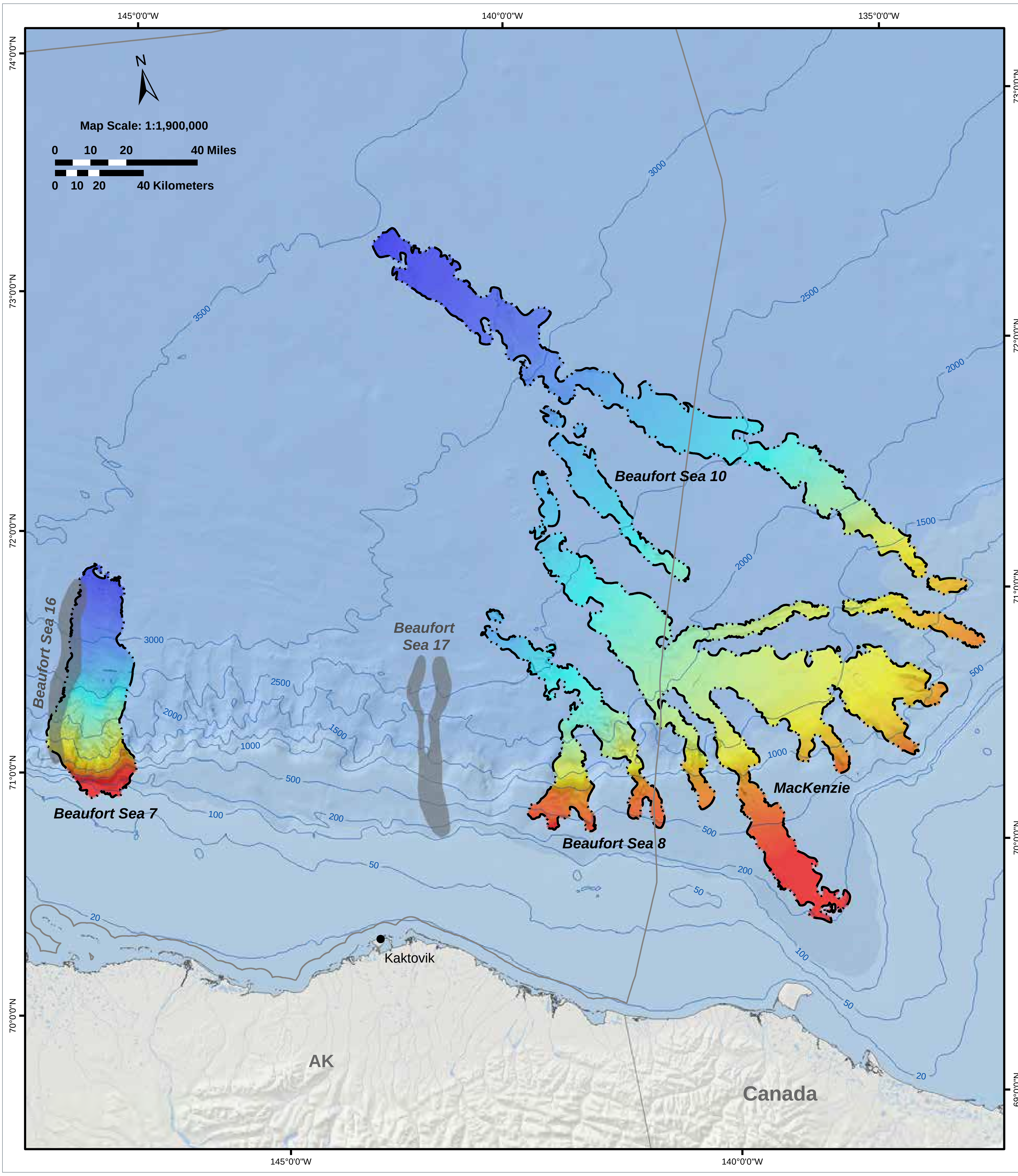


NOTABLE FACTS

The flow of nutrient-rich waters along the west wall enhances the abundance of burrowing benthic organisms, which in turn promote high bioerosion of the canyon wall (Eittreim et al. 1982).

The confluence of different water masses near Barrow Canyon promote high biological productivity in the area (Shroyer 2012). At high latitudes, Barrow Canyon and all Beaufort and Chukchi Sea canyons are connected to shelf systems that are highly productive during seasonal ice melting and open-water periods (Grebmeier et al. 2006). Seasonal changes in water temperature and salinity enable Barrow Canyon to be a hotspot for biological communities (Shroyer 2012).

MACKENZIE AND BEAUFORT SEA
CANYONS 7, 8, AND 10



NOTABLE FACTS

The Canadian Beaufort Sea continental shelf is characterized by three major bathymetric depressions, including the MacKenzie cross-shelf trough, which is the former location of ice streams that drained the northwest margin of the Laurentide Ice Sheet during Quaternary full-glacial periods (Geological Survey of Canada 1972).

In the deeper waters of the Beaufort Sea (Canada Basin) and over the continental margin and slope, large-scale circulation features include the Beaufort Gyre, the Beaufort Undercurrent, and the intrusion of Atlantic waters. These features, combined with the effects of regional winds and the MacKenzie River plume, create a complex of regional surface currents (Fissel et al. 2013).

Bowhead and beluga whale occur within waters near these canyons on a seasonal basis (Moors-Murphy 2014).

Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

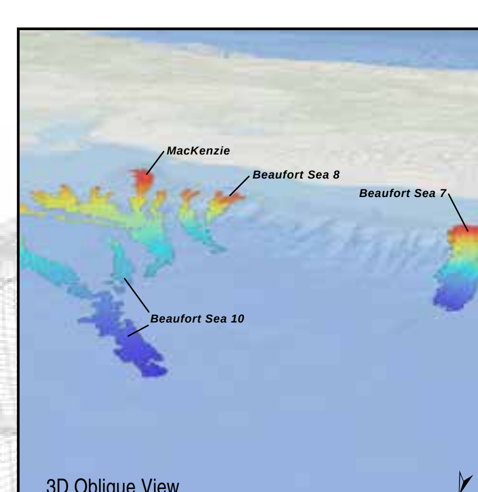
Submarine Canyon Bathymetry

60 1770 3470

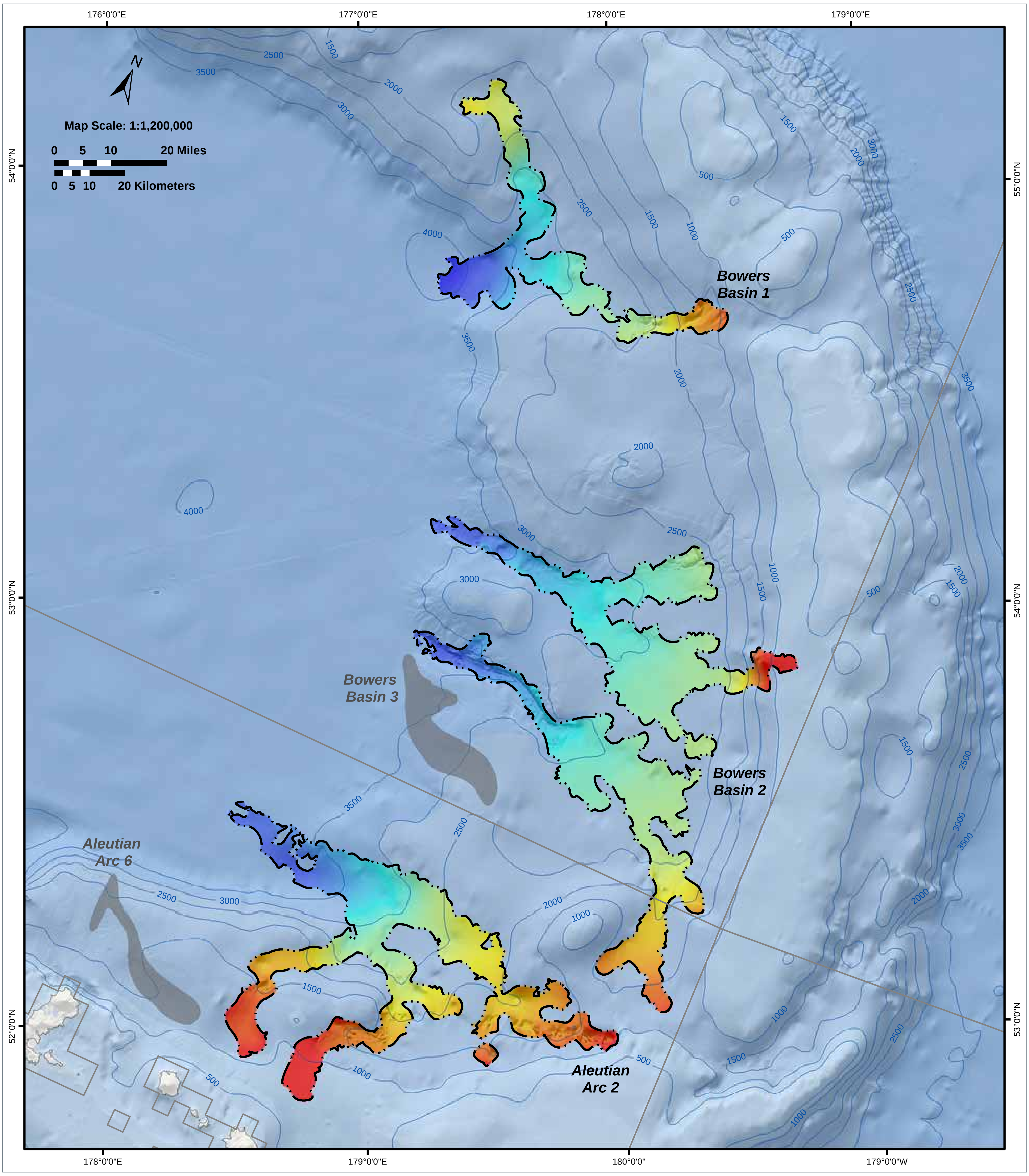
Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management



ALEUTIAN ARC 2 AND BOWERS BASIN CANYONS 1 AND 2



NOTABLE FACTS

- Younger strata in the Aleutian Basin seem to be draped over basement relief and composed of oceanic crust, probably of Cretaceous age. Volcanism occurred on the basin margins throughout most of the Cretaceous Period and Cenozoic Era (Wiley 1986).
- The deep waters of the southern Bering Sea contain biological communities distinct from the adjacent Aleutian Island shelf (Batten et al. 2006).
- Prior to management actions in the area of these canyons, it was estimated that, from 1997 to 1999, Alaska groundfish fisheries (bottom trawling) removed an extrapolated average of approximately 40 metric tons of coral yearly in the Bering Sea and Aleutian Islands (Hourigan 2009).

Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

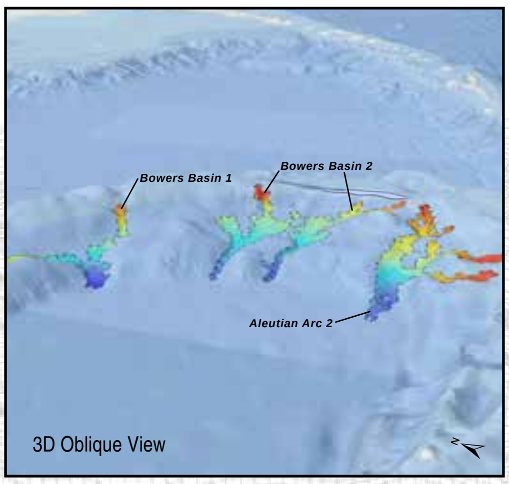
Submarine Canyon Bathymetry

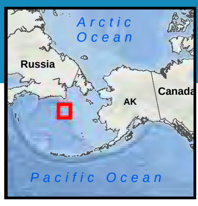
700 2430 4150

Depth in meters

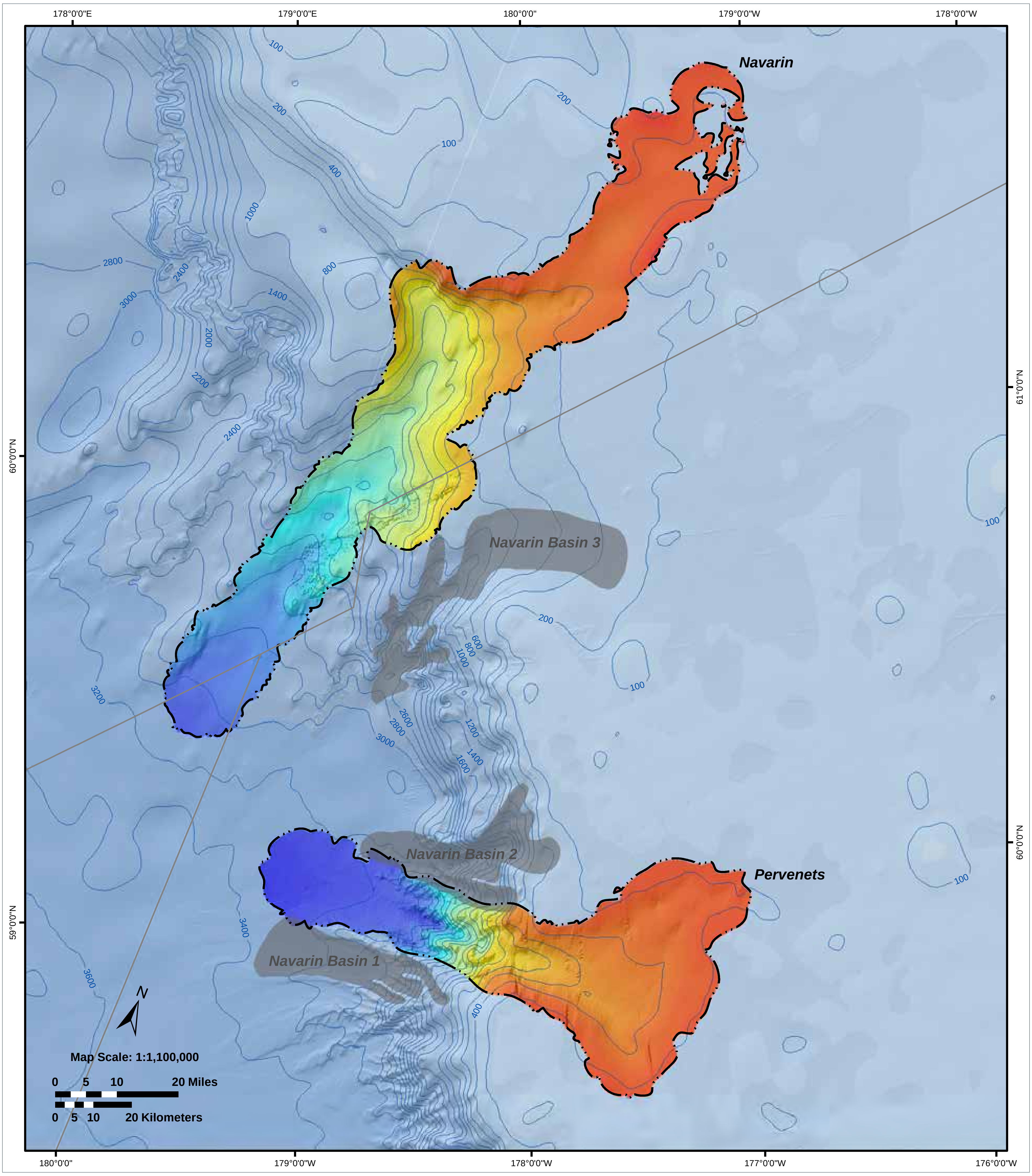
Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management





NAVARIN AND PERVENETS CANYONS



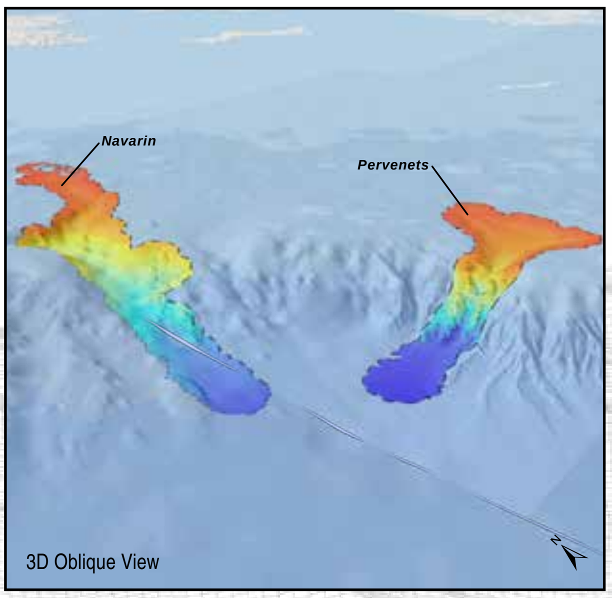
NOTABLE FACTS

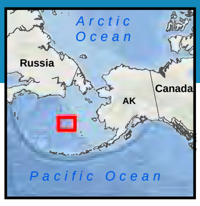
Navarin Canyon has two main branches and does not lead to any distinct submarine fan morphology, suggesting that it has not been effective as a major conduit for sediment transport from the continent (Normark and Carlson 2003).

Skates (Rajidae) have been reported to deposit their large leathery egg cases in specific canyon areas, with 10 of 14 identified nursery sites reported at the heads of 5 large canyons in the Bering Sea, including Navarin Canyon (VanPelt 2015).

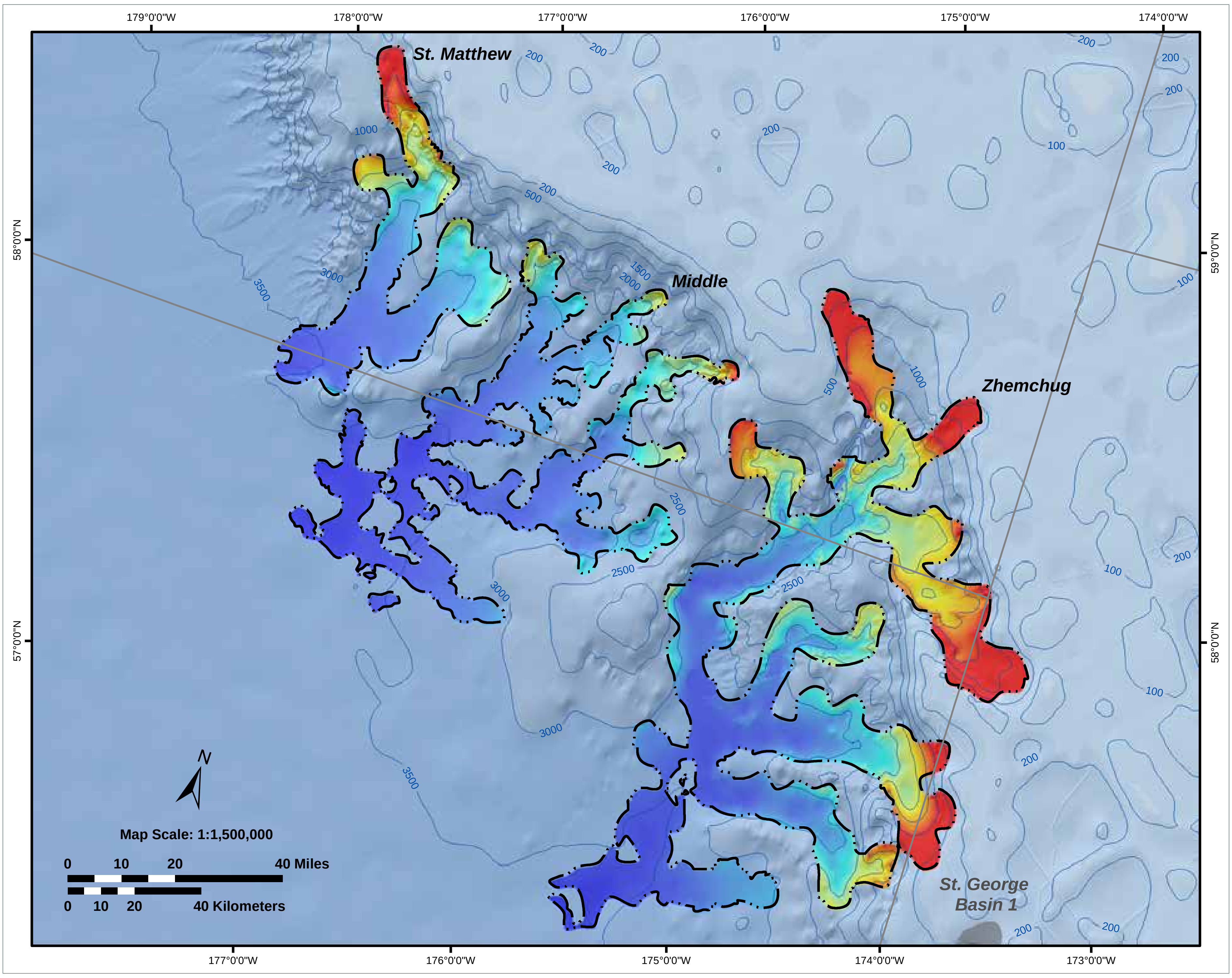
Canyons (such as Navarin and Pervenets) that indent the shelf break can interrupt along-slope currents and may create unique physical environments compared to the adjacent slope (Sigler et al. 2015).

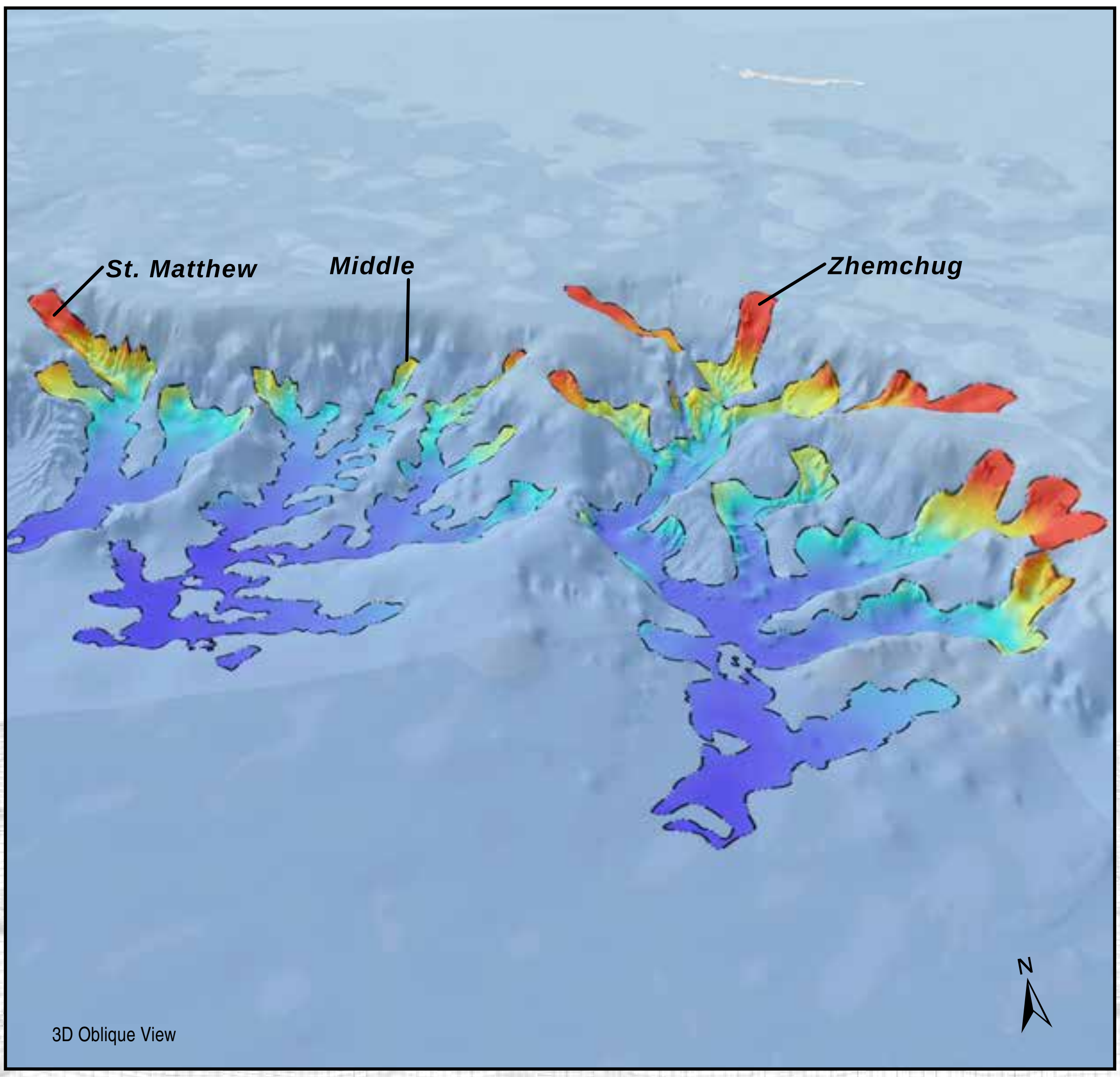
Bathymetric Contour (m)
BOEM Planning Area Boundary
Canyon Boundary
CSA Ocean Sciences Inc. et al. 2019 Delineation Method
Harris et al. 2014 Delineation Method
Submarine Canyon Bathymetry
80 1730 3370
Depth in meters
Coordinate System:
Alaska Albers Equal Area Conic
BOEM Bureau of Ocean Energy Management





ST. MATTHEW, MIDDLE, AND ZHEMCHUG CANYONS





Bathymetric Contour (m)
BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method
Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

90 1880 3660
Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management

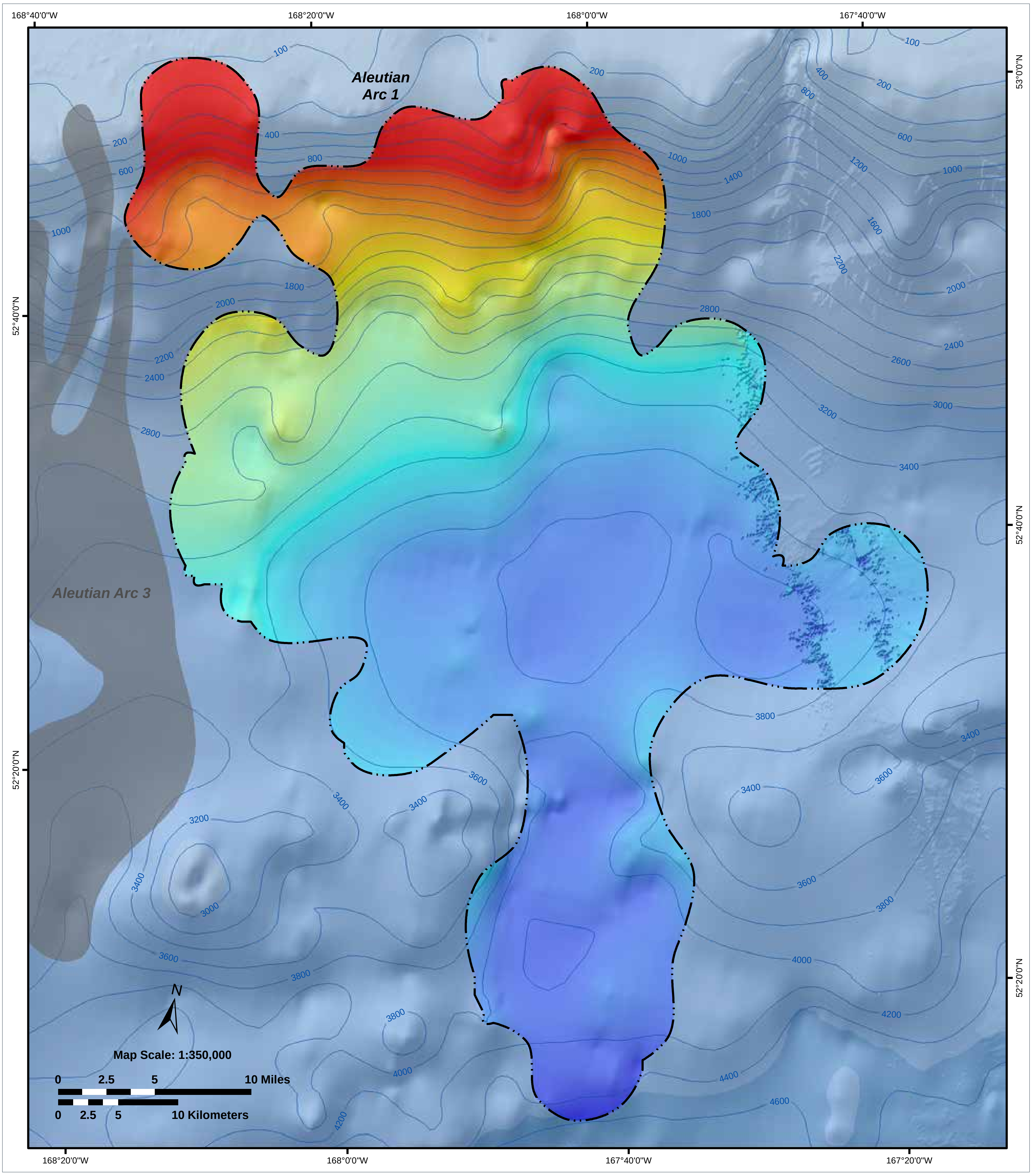
NOTABLE FACTS

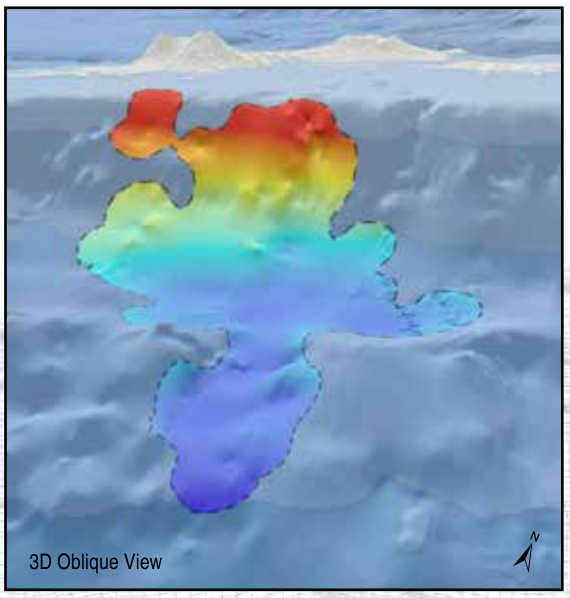
Canyons of the eastern Bering Sea slope support a rich fauna, comprising marine birds, mammals, fish, and benthic invertebrates on hard substrates (Miller et al. 2012; Sigler et al. 2015). Populations of the rare and endangered short-tailed albatross (*Phoebastria albatrus*) are known to concentrate at the head of St. Matthew Canyon due to availability of prey (Piatt et al 2006).

The area has been called the "Bering Sea Green Belt" to describe its productivity, due to the abundance of phytoplankton, zooplankton, squids, fishes, birds, and mammals along this shelf edge (Zimmermann and Prescott 2018).

Zhemchug Canyon was likely excavated in the Pleistocene by mass wasting, slumping, and creeping of sediment accumulated at the heads of the Yukon and Kuskokwim Rivers during periods of glacially lowered sea level (Miller et al. 2012).

ALEUTIAN ARC 1 CANYON





Bathymetric Contour (m)

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Harris et al. 2014 Delineation Method

Submarine Canyon Bathymetry

100 2360 4610

Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

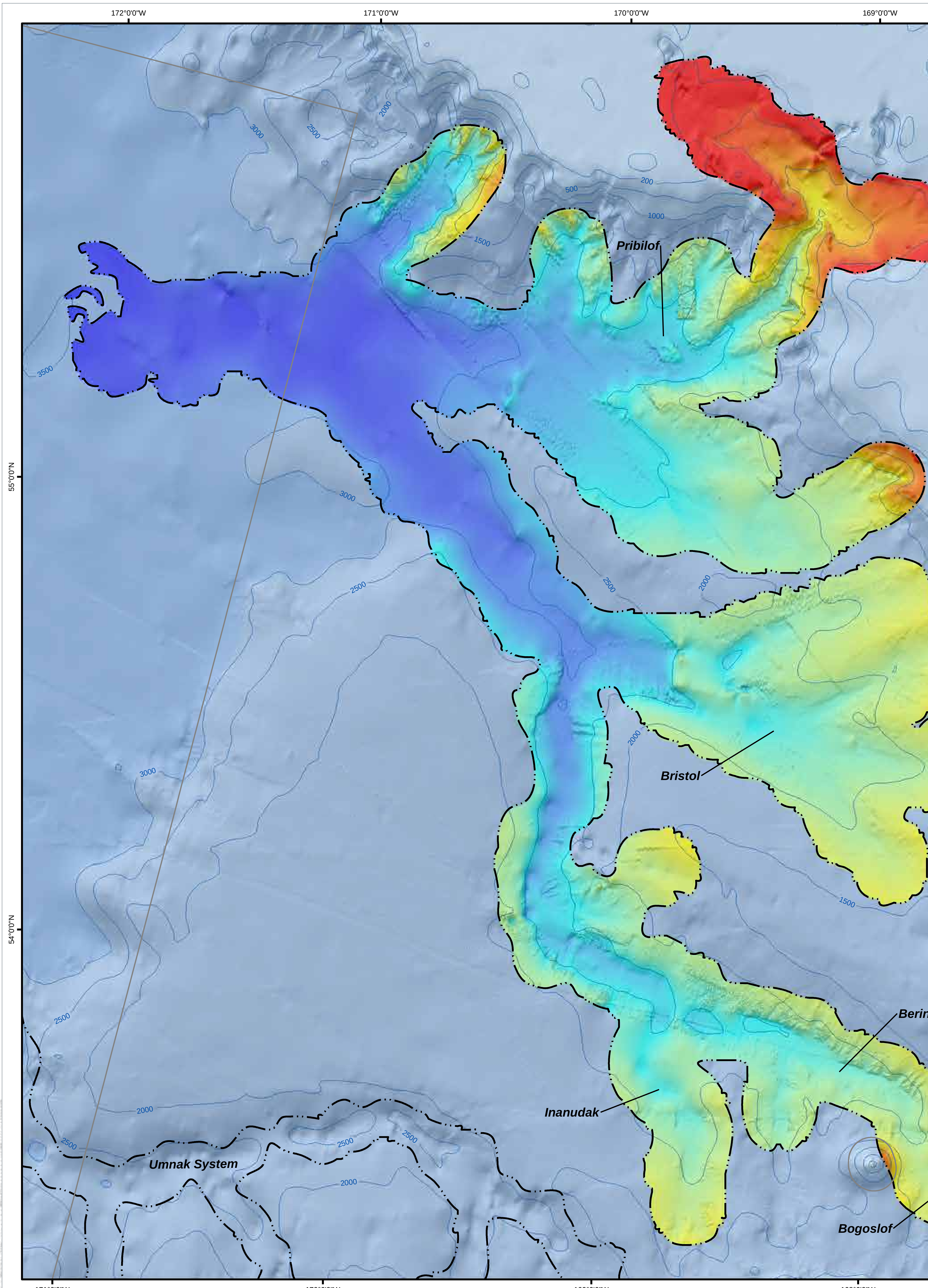
BOEM Bureau of Ocean Energy Management

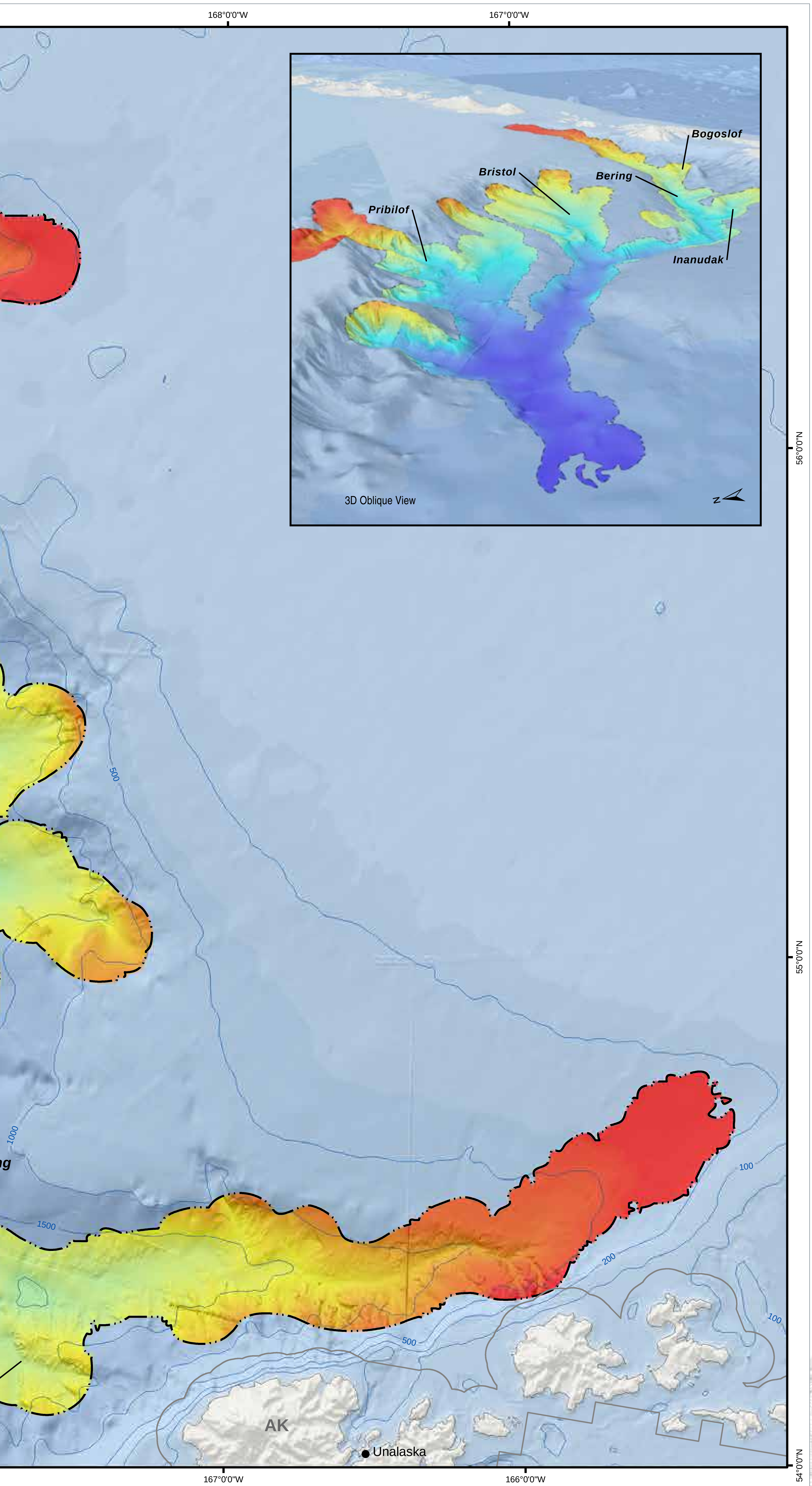
NOTABLE FACTS

Corals in the Gulf of Alaska, including red tree coral, black coral, and hydrocorals, are known to occur along the continental shelf edge in hard bottom habitat. ROV cruises and habitat suitability studies indicate various coral and sponge species may be found at the head of this canyon (Rooper et al. 2017). In some places, such as the central and western Aleutian Islands, deep sea coral and sponge resources can be extremely diverse and may rank among the most abundant deep sea coral and sponge communities in the world (Rooper et al. 2017).

To protect the Steller sea lion, NMFS closed all Alaska Atka Mackerel fisheries in this region in 1990 (50 CFR 679).

BERING CANYON SYSTEM





NOTABLE FACTS

Pribilof, Bristol, Bering, Bogoslof, Inanudak, and Pribilof Canyons comprise a system of features that share a common mouth within the Aleutian Basin (Miller et al. 2012).

Pribilof Canyon was likely excavated in the Pleistocene by mass wasting, slumping, and creeping of sediment accumulated at the heads of the Yukon and Kuskokwim rivers during periods of glacially lowered sea level (Miller et al. 2012). Bering Canyon is characterized by a wide slope valley (Duffy-Anderson et al. 2013). A fan channel extending basinward from Bering Canyon extends several hundred kilometers into the Aleutian Basin as a low-relief (10 to 20 m), very broad (20 km), and flat-floored turbidite channel. The Bering Fan lacks the distinctive fan morphologic expression that is generally present on other fans; instead, it forms a relatively thin veneer of sediment in the Aleutian Basin.

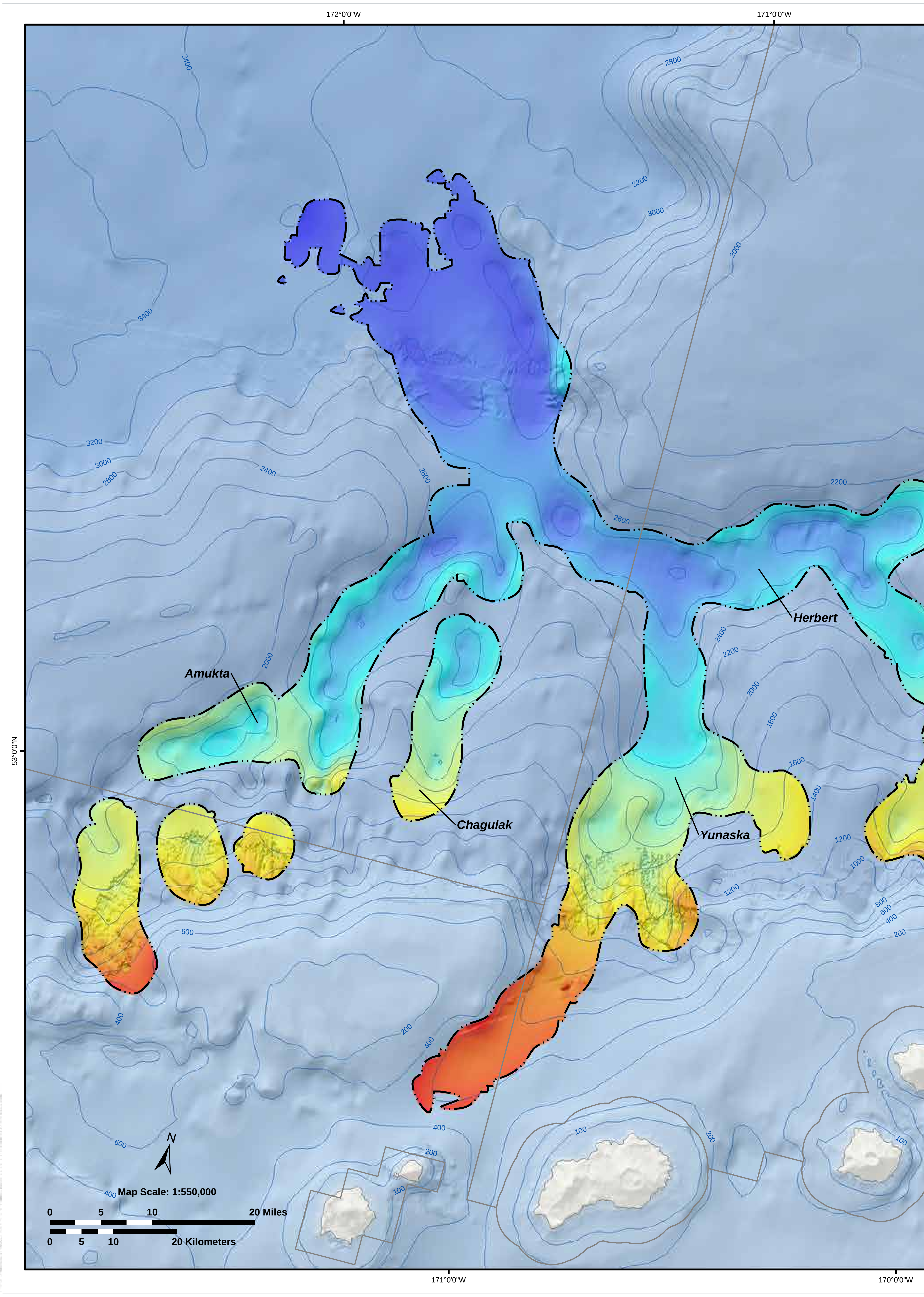
The eastern Bering Sea slope and outer shelf is a region of enhanced primary and secondary productivity (the "Bering Sea Green Belt") and attracts large numbers of fish, seabirds, and marine mammals. Productivity is enhanced in this region because of physical processes at the shelf break, which include intensive tidal mixing, and transverse circulation and eddies in the Bering Slope Current; collectively, these bring nutrients into the local photic zone (Sigler et al. 2015).

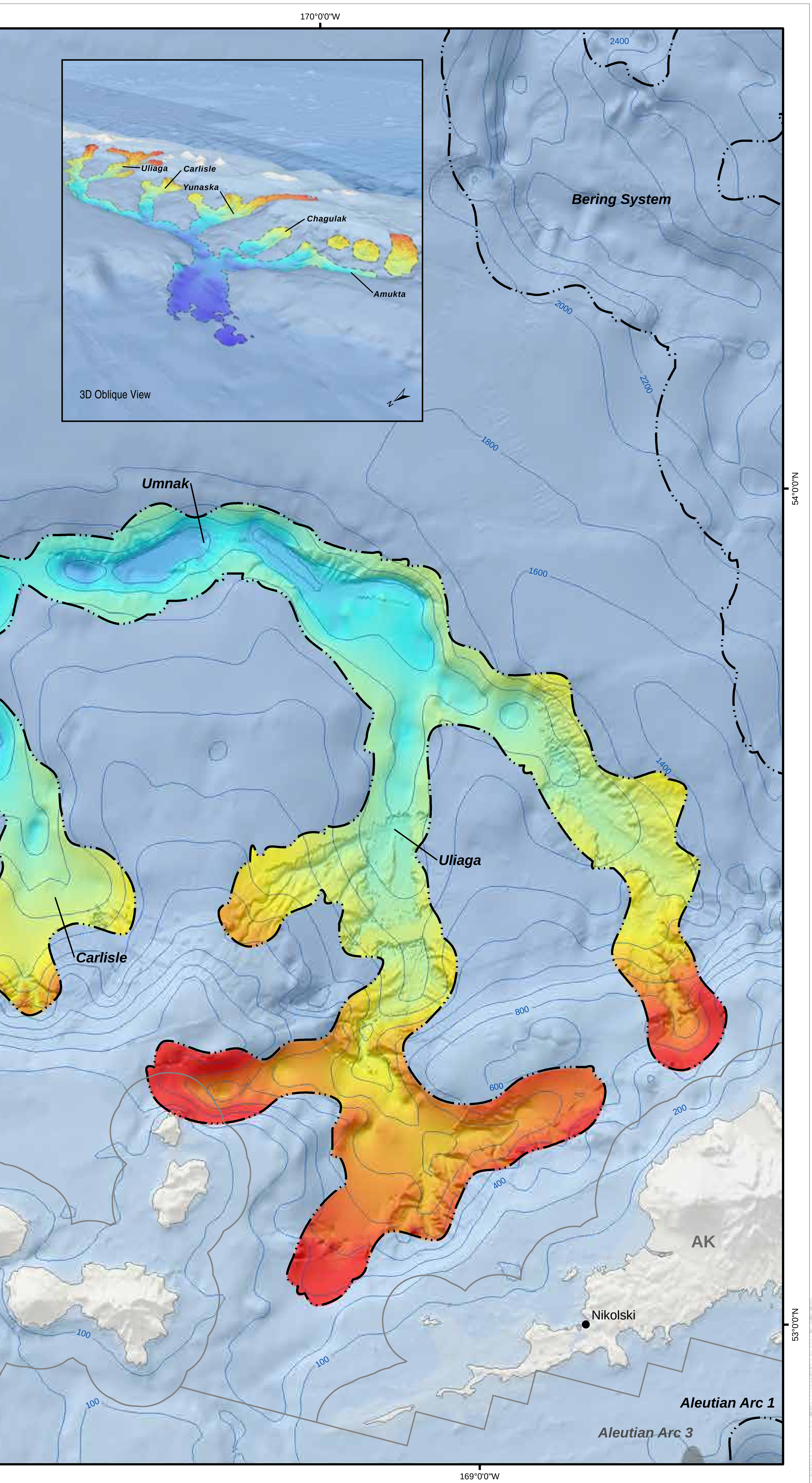
Pribilof canyon and adjacent continental shelf slope form important spawning grounds for several fish species including skates, rockfishes, smooth tongues, and flatfishes. Other fish species that have been observed in the canyon include Greenland halibut, Pacific Ocean perch, cottids, zoarcids, agonids, and the giant grenadier (Miller et al. 2012).

Commercial fishing activities pose a risk to benthic communities in Bering Sea Canyons through seafloor disturbance from trawling and marine debris from loss of gear (Miller et al. 2012; MacLean et al. 2017).

The following shipwrecks are believed to be located within Bering Canyon, in addition to four unnamed wrecks: F/V *America Star*, F/V *Desperado*, *Maren 1*, *T&T*, *KP21*, *Qanirtuuq Princess*, F/V *Genie Maru No.7*, *Cecilia barge*, *Akutan* (NOAA 2019).

UMNAK CANYON SYSTEM





NOTABLE FACTS

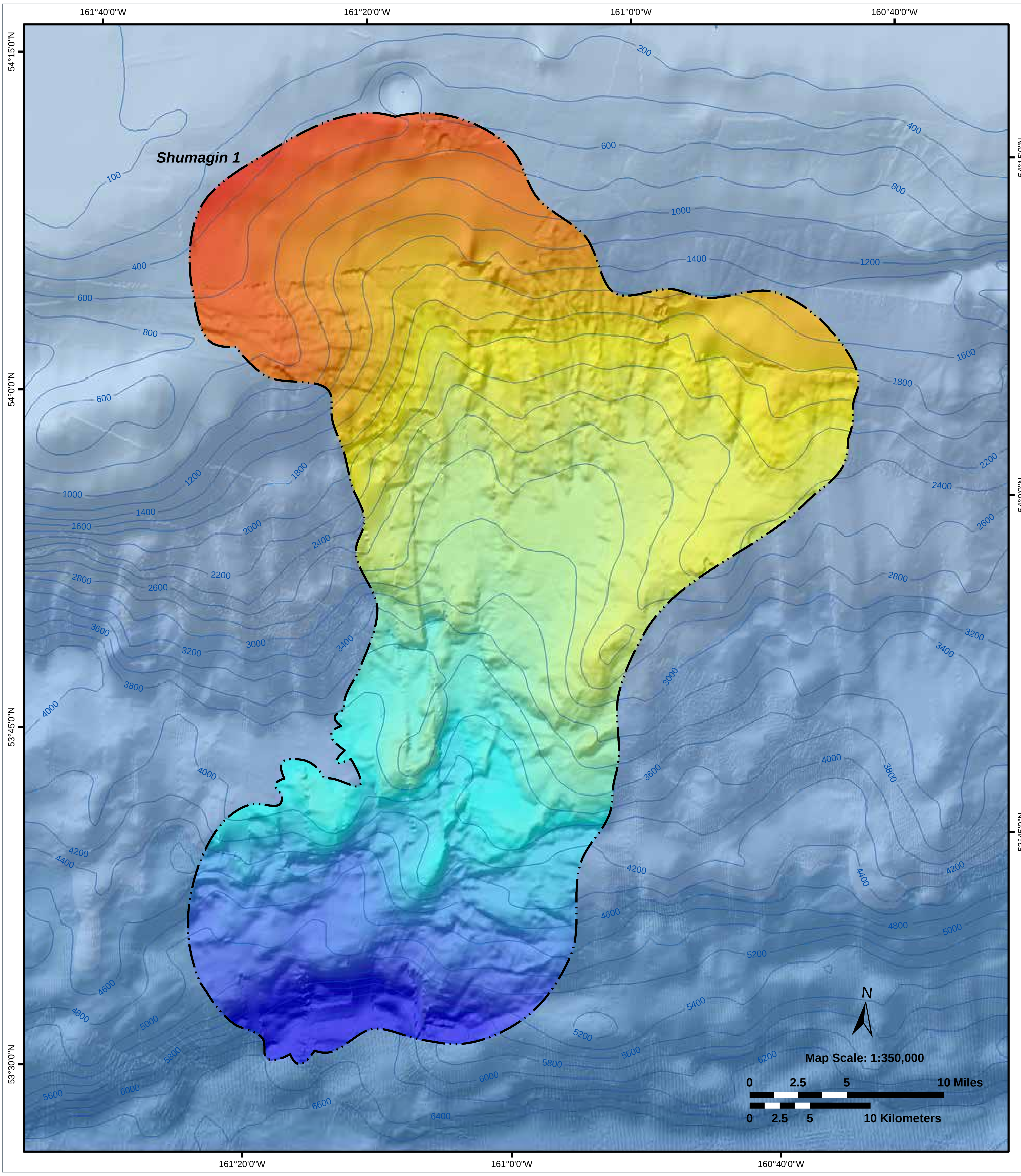
The Umnak Canyon system includes Uliaga, Umnak, Carlisle, Herbert, Yunaska, Chagulak, and Amukta Canyons, which run roughly parallel to the Aleutian Islands.

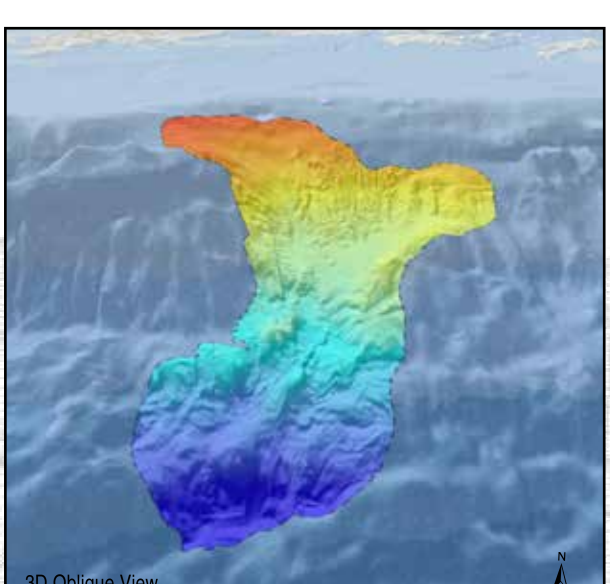
The eastern Bering Sea shelf consists of inner, middle, and outer shelf ecological zones separated by oceanographic fronts associated with the 50-, 100-, and 200-m isobaths, respectively, each of which possesses fundamentally different physical processes and species compositions (Aydin et al. 2002).

The eastern Bering Sea slope and outer shelf is a region of enhanced primary and secondary productivity and attracts large numbers of fish, seabirds, and marine mammals.

Productivity is enhanced in this region because of physical processes at the shelf break, which include intensive tidal mixing, and transverse circulation and eddies in the Bering Slope Current; collectively, these bring nutrients into the local photic zone (Sigler et al. 2015).

SHUMAGIN 1 CANYON





Bathymetric Contour (m)

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

290 3350 6410

Depth in meters

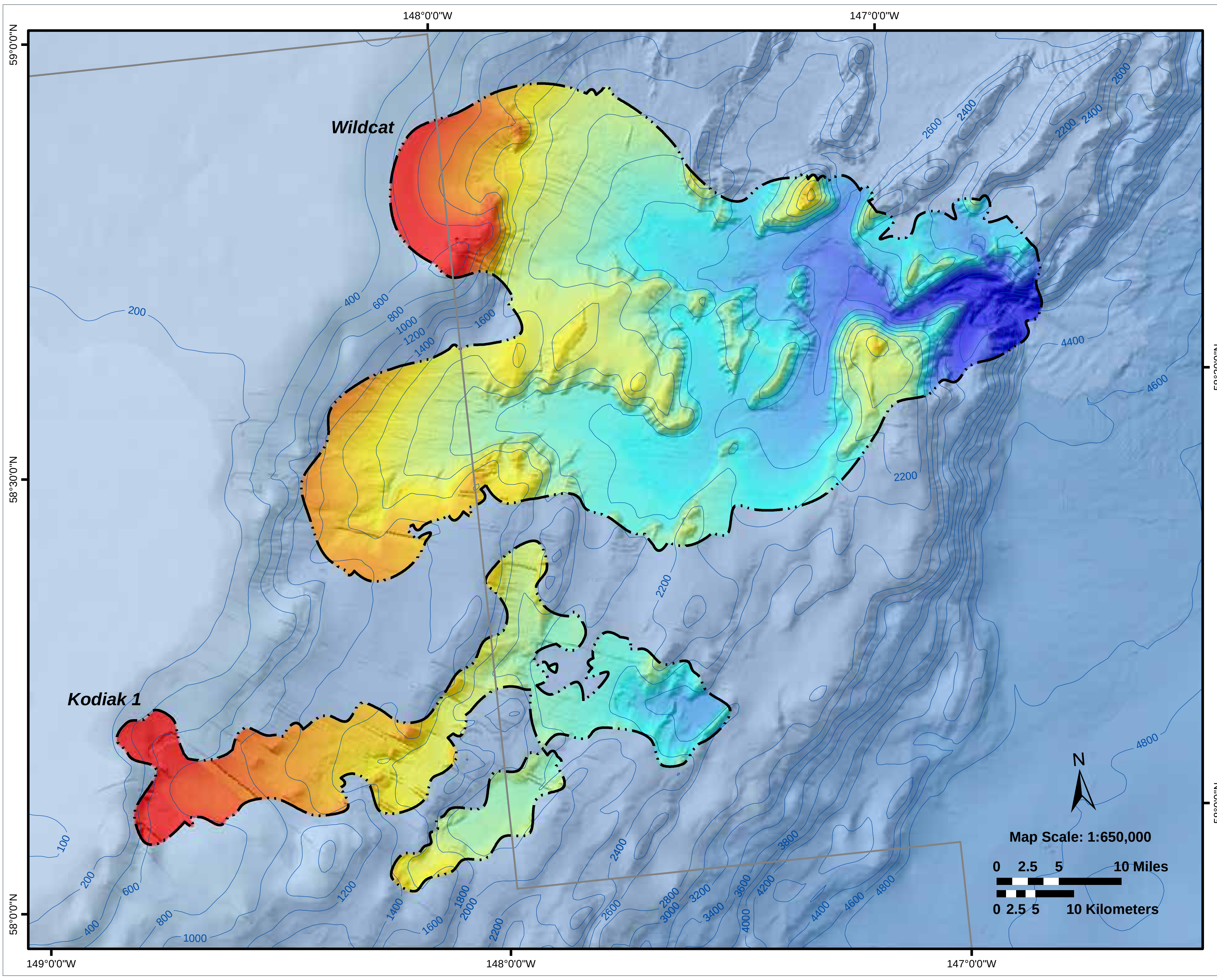
Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

- Dredge samples taken from the outer wall of this canyon indicate limestone and sedimentary rock with carbonate cement (Horowitz et al. 1989).
- Flow in this basin, primarily driven by the Alaska Coastal Current (ACC), is affected by the canyons in this region, which funnel energy from the ACC and contribute to strong tidal mixing (Bailey et al. 2008).
- The canyon's influence over regional circulation patterns facilitates the distribution of fish eggs and larvae from deeper slope waters up onto the continental shelf (Bailey et al. 2008).

KODIAK 1 AND WILDCAT CANYONS



Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

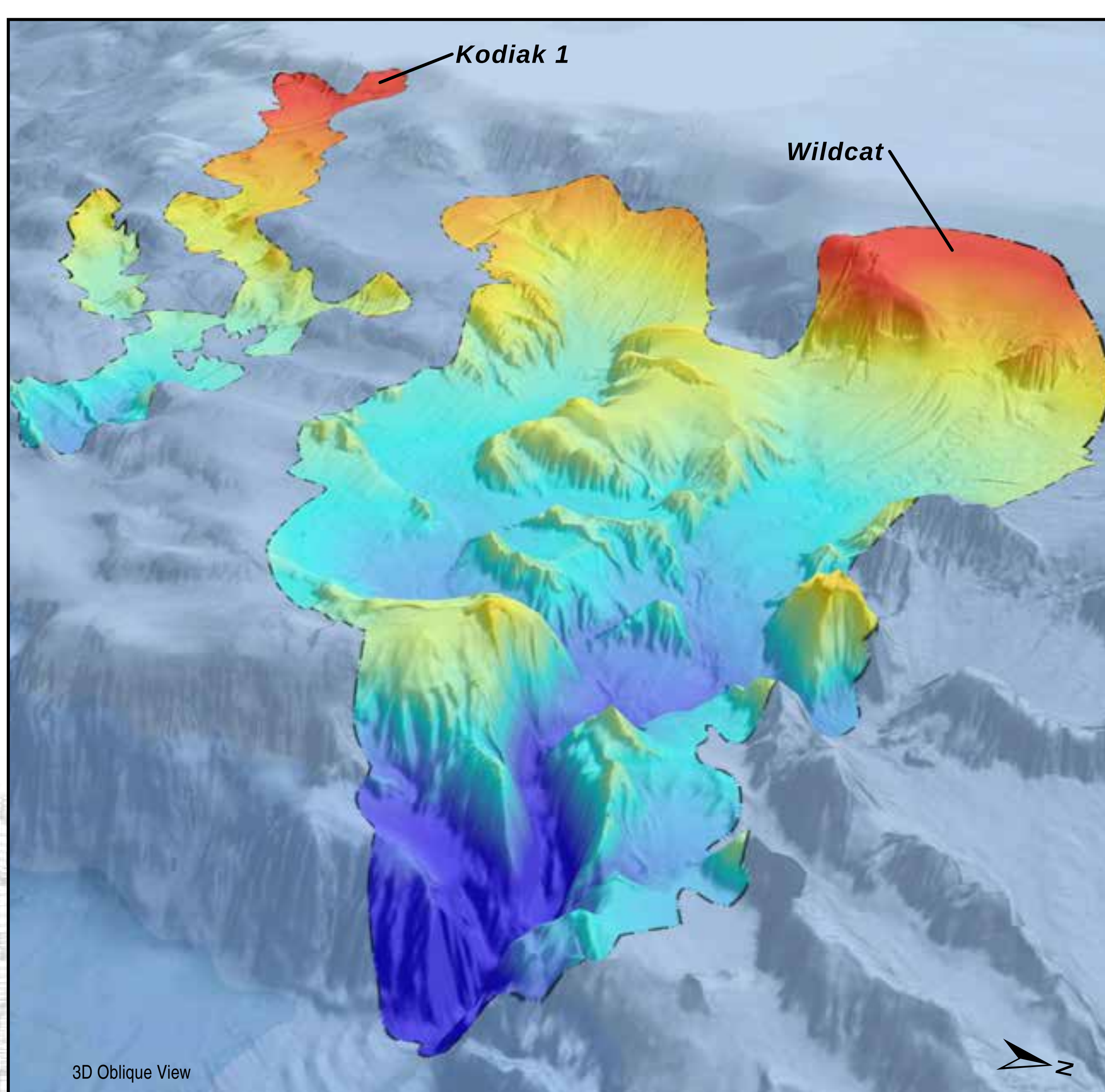
Submarine Canyon Bathymetry

300 2390 4470

Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management

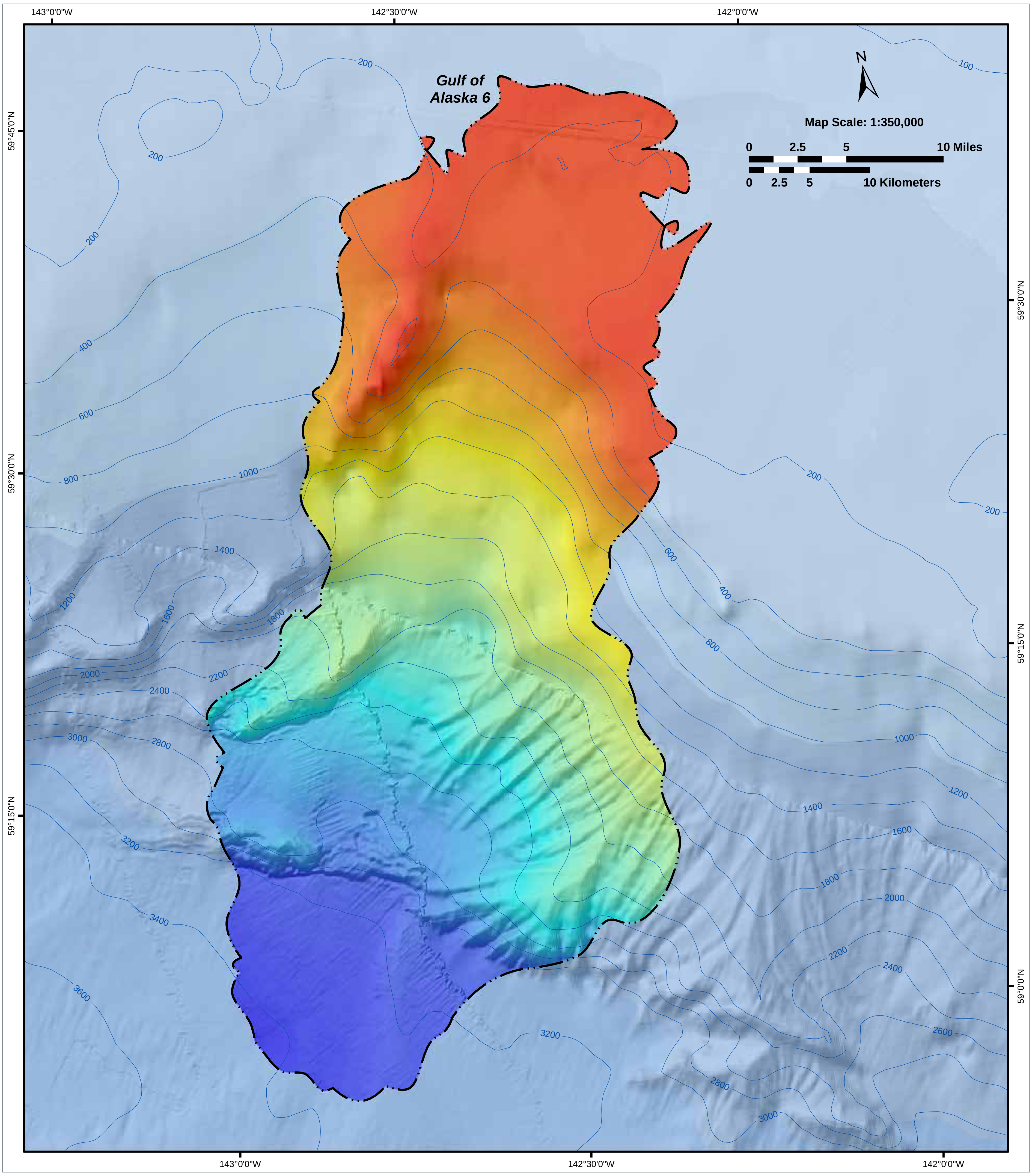


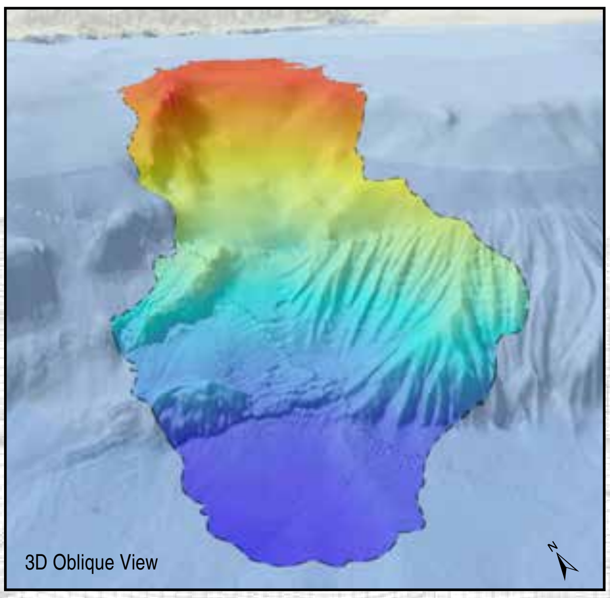
NOTABLE FACTS

Submarine canyons play a key role in cross-shelf transport of heat, salt, and nutrients, and flow in this basin is primarily driven by the Alaska Coastal Current (Mordy et al. 2019).

Waters around Kodiak Island and the Kenai Peninsula are valuable nursery habitat for fish in the area due to submarine canyons facilitating the transport of fish larvae from deeper slope waters onto the continental shelf (Doyle et al. 2019; Mordy et al. 2019).

GULF OF ALASKA 6 CANYON





Bathymetric Contour (m)

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

110 1780 3440

Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

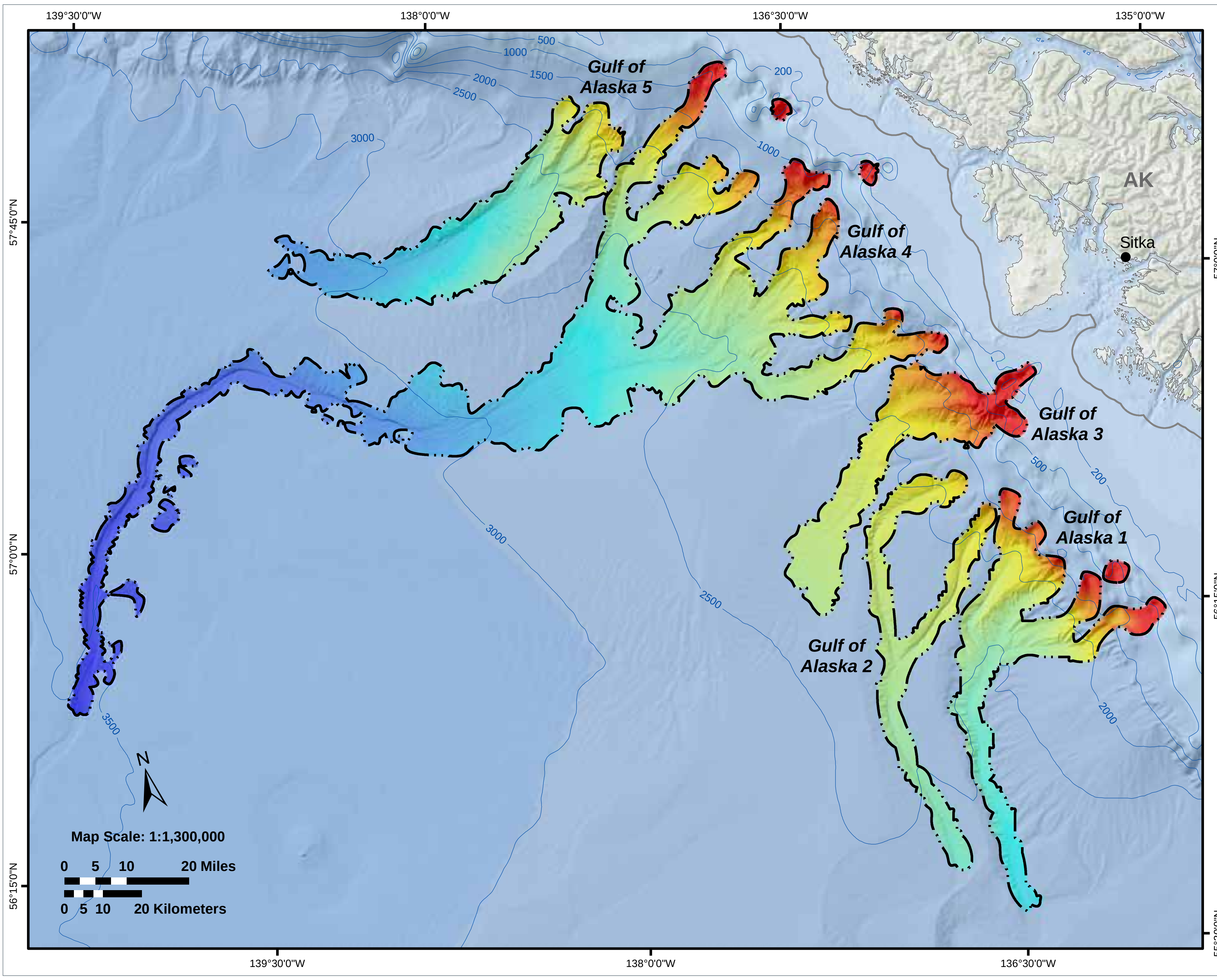
BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

Flow in this basin is primarily driven by the Alaska Coastal Current, a prominent feature in this region, and is often affected by submarine canyons, which can disrupt coastal flow and may facilitate the flow of nutrient rich water onto the shelf (Mordy et al. 2019).

Corals in the Gulf of Alaska, including red tree coral, black coral, hydrocorals, and sponges, are known to occur along the continental shelf edge in hard bottom habitat. ROV cruises and habitat suitability studies indicate these species may be found in this canyon (Rooper et al. 2017).

GULF OF ALASKA CANYONS 1 to 5



Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

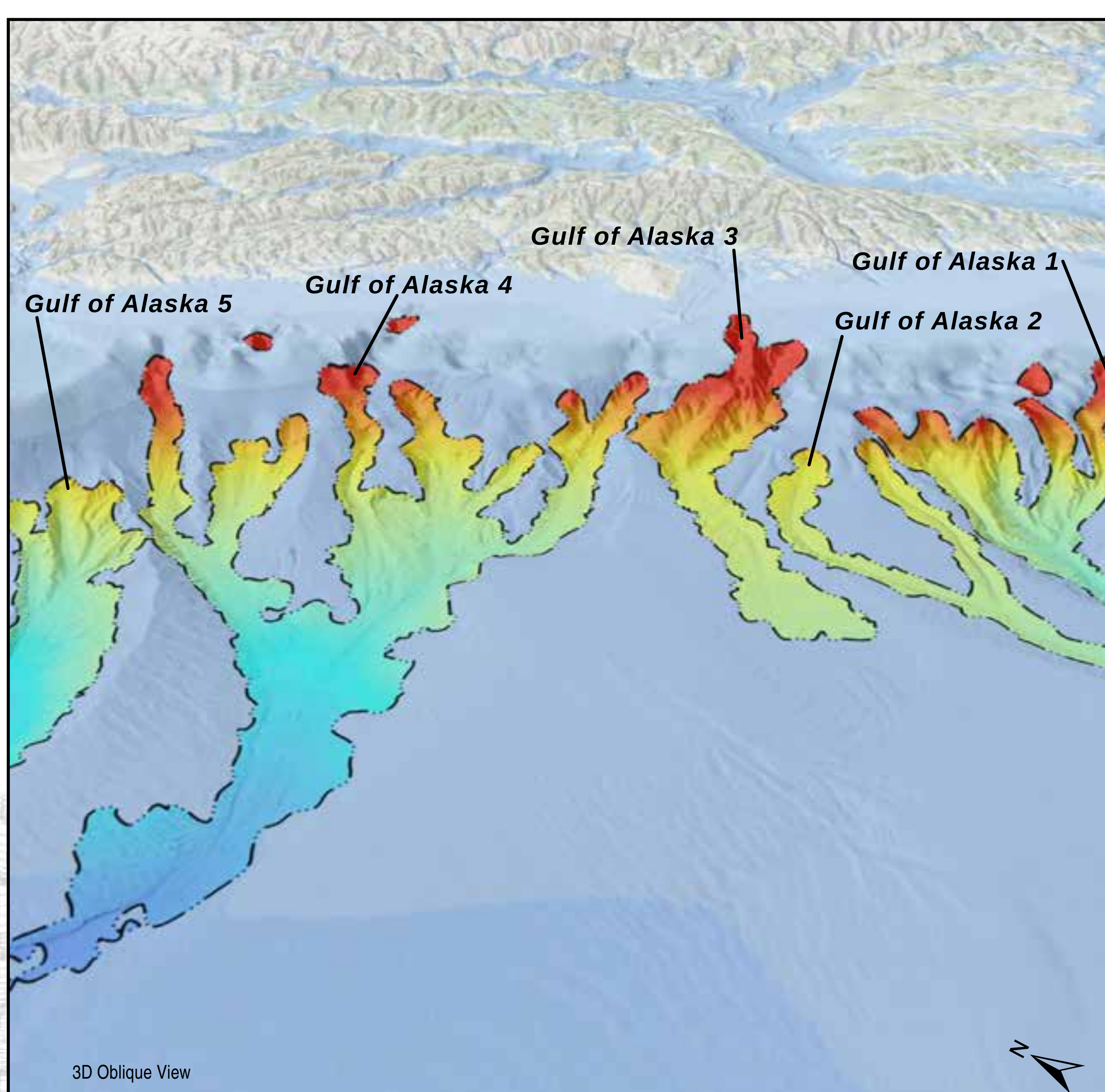
Submarine Canyon Bathymetry

180 1880 3570

Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management

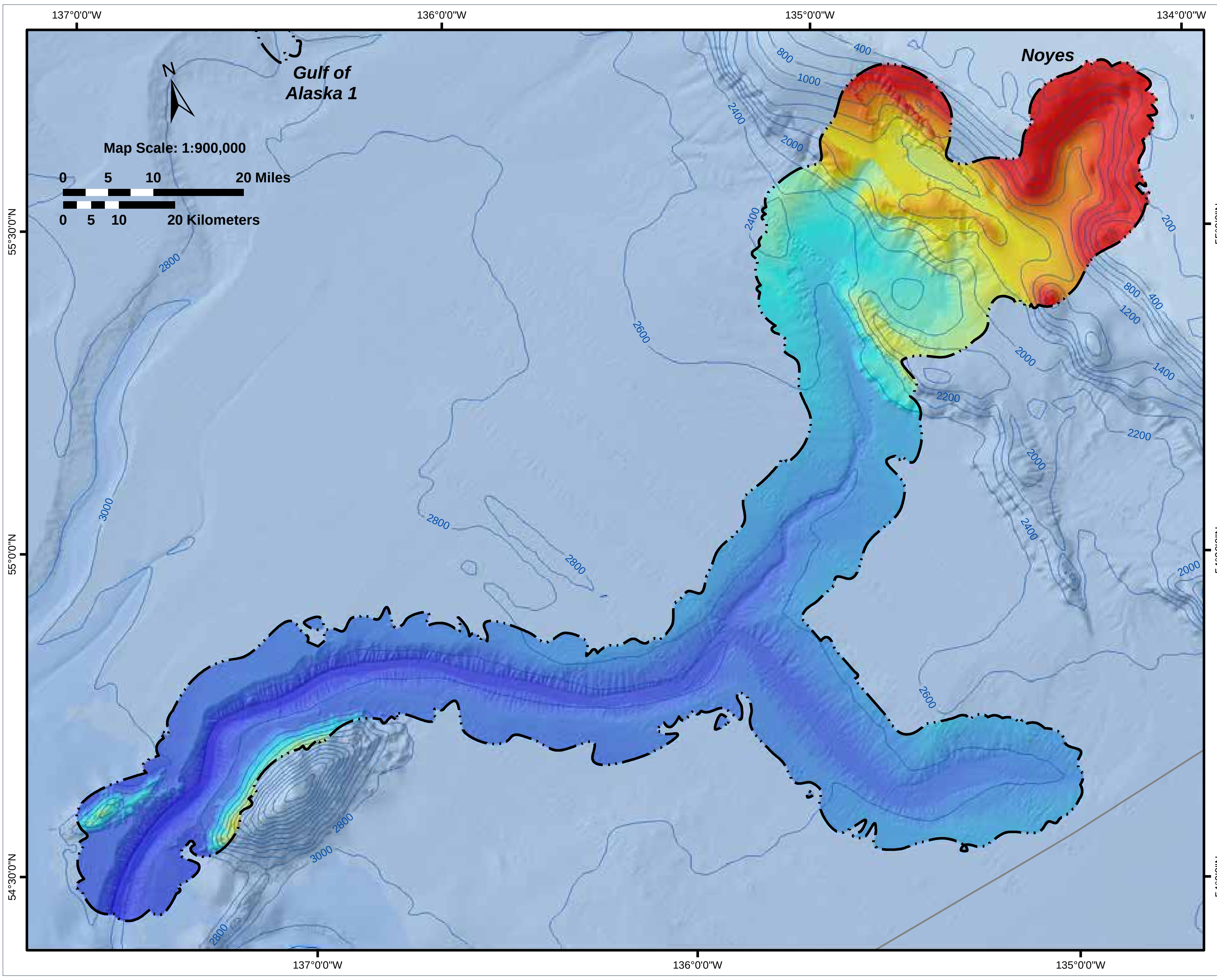


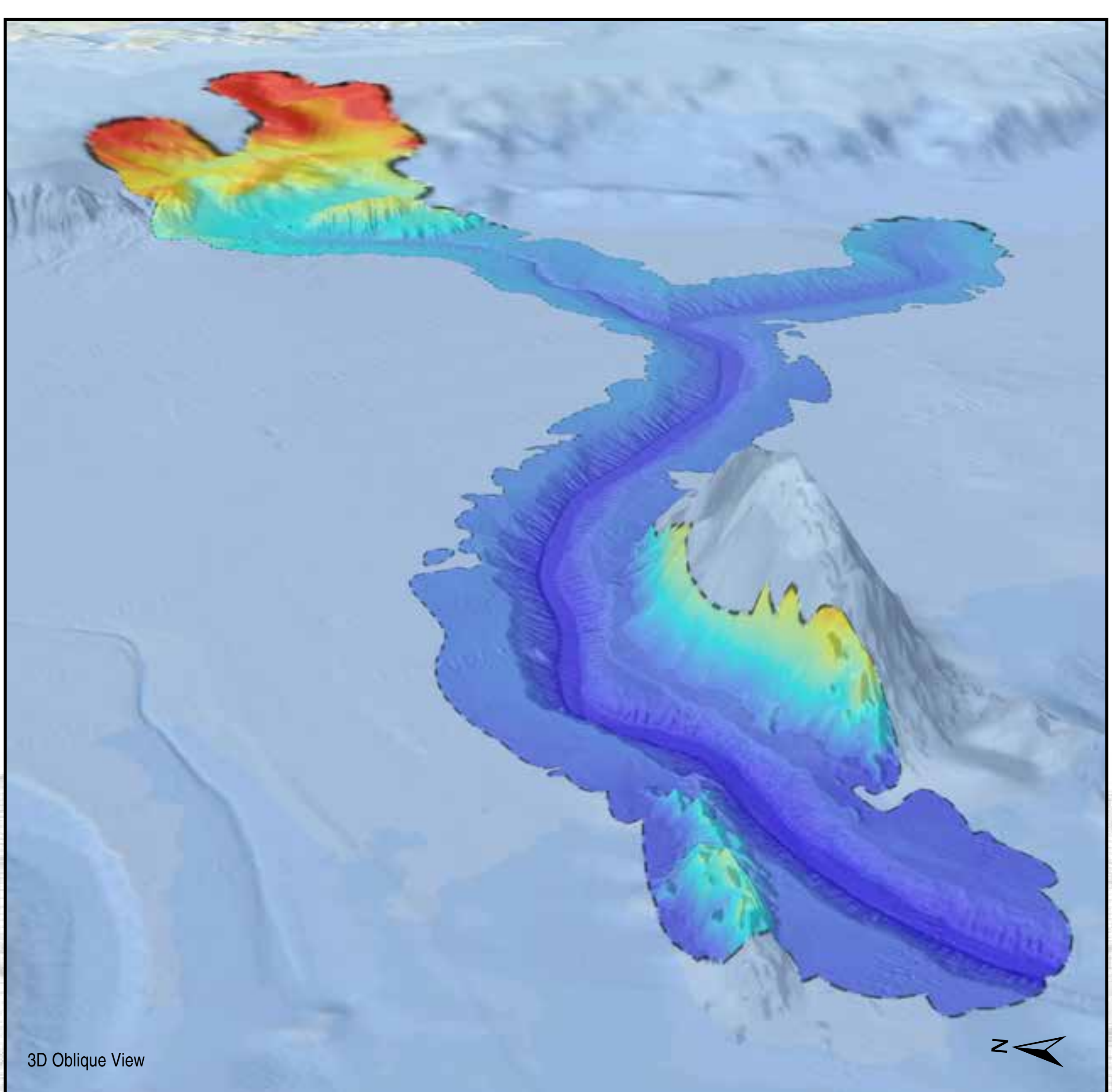
3D Oblique View

NOTABLE FACTS

- Gulf of Alaska 5 Canyon sits on the Queen Charlotte Fault line in southeastern Alaska (Brothers et al. 2018).
- Bottom trawling has been banned in this region since 1998 to protect deep sea coral species.
- The floors of these canyons contain well-defined bedforms or sediment waves located down-canyon of small scarps. This area is susceptible to frequent landslides, which transform into debris flows that are funneled through the canyons (Brothers et al. 2018).

NOYES CANYON





3D Oblique View

Bathymetric Contour (m)

BOEM Planning Area Boundary

Canyon Boundary

CSA Ocean Sciences Inc. et al. 2019 Delineation Method

Submarine Canyon Bathymetry

130 1690 3240

Depth in meters

Coordinate System:
Alaska Albers Equal Area Conic

BOEM Bureau of Ocean Energy Management

NOTABLE FACTS

This canyon sits on the Queen Charlotte Fault Line, an active fault line that contributes to changes in geologic features in the region (Brothers et al. 2018).

Dickins Seamount is located approximately 16 km southwest of the lower part of the canyon, around which numerous species of gorgonian corals and glass sponges have been observed during deep sea research cruises conducted by NOAA. Gorgonian coral within the canyon itself have been observed on the shelf slope closer to the head of the canyon.

A possible shipwreck was identified approximately 3 km north of this canyon in water depths between 2,000 and 3,000 m (NOAA 2019).

CITATIONS

Atwater T. 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. Geological Society of America Bulletin 81:3513-3536.

Audubon Alaska, Oceana, Ocean Conservancy, Pew Charitable Trusts, World Wildlife Fund. 2016. A synthesis of important areas in the U.S. Chukchi and Beaufort Seas: best available data to inform management decisions. 236 p.

Aydin KY, Lapki VV, Radchenko VI, Livingston PA. 2002. A comparison of the eastern bering and western sea shelf and slope ecosystems through the use of mass-balance food web models. Seattle, WA. No. NOAA Technical Memorandum NMFS-AFSC-130.

Bailey KM, Abookire AA, Duffy-Anderson JT. 2008. Ocean transport paths for the early life history stages of offshore-spawning flatfishes: a case study in the Gulf of Alaska. Fish Fish. 9(1):44-66.

Batten SD, Hyrenbach KD, Sydeman WJ, Morgan KH, Henry MF, Yen PPY, Welch DW. 2006. Characterising meso-marine ecosystems of the north Pacific. Deep-Sea Res Pt II. 53(3-4):270-290.

Bosley KL, Lavelle JW, Brodeur RD, Wakefield WW, Emmett RL, Baker ET, Rehmke KM. 2004. Biological and physical processes in and around Astoria submarine canyon, Oregon, USA. J Mar Syst. 50:21-37.

Brooke SD, Watts MW, Heil AD, Rhode M, Mienis F, Duineveld GCA, Davies AJ, Ross SW. 2017. Distributions and habitat associations of deep-water corals in Norfolk and Baltimore Canyons, Mid-Atlantic Bight, USA. Deep-Sea Res Pt II. 137:131-147.

Brothers DS, Andrews BD, Walton MAL, Greene HG, Barrie JV, Miller NC, ten Brink U, East AE, Haeussler PJ, Kluesner JW et al. 2018. Slope failure and mass transport processes along the Queen Charlotte Fault, southeastern Alaska. J Geol Soc, London Special Publications. 477:SP477.430.

Butman B, Twichell DC, Rona PA, Tucholke BE, Middleton TJ, Robb JM. 2006. Map: seafloor topography and backscatter intensity of the Hudson Canyon region offshore of New York and New Jersey. U.S. Geological Survey.

Carlson PR, Karl HA. 1984. Discovery of two new large submarine canyons in the Bering Sea. Mar Geol. 56(1-4):159-179.

Coleman JM, Prior DB, Lindsay JF. 1982. Formation of the Mississippi Canyon. Gulf Coast Association of Geological Societies Transactions. 32:519.

Conrad TA, Nielsen SG, Peucker-Ehrenbrink B, Blusztajn J, Winslow D, Hein JR, Paytan A. 2017. Reconstructing the evolution of the submarine Monterey Canyon system from Os, Nd, and Pb isotopes in hydrogenetic Fe-Mn crusts. Geochem Geophys. 18(11):3946-3963.

Covault JA, Fildani A, Romans BW, McHargue T. 2011. The natural range of submarine canyon-and-channel longitudinal profiles. Geosphere. 7(2):313-332.

CSA Ocean Sciences Inc., Ross SW, Brooke S, Baird E, Coykendall E, Davies A, Demopoulos A, France S, Kellogg C, Mather R, Mienis F, Morrison C, Prouty N, Roark B, Robertson C. 2017. Exploration and research of mid-Atlantic deepwater hard bottom habitats and shipwrecks with emphasis on canyons and coral communities: Atlantic deepwater canyons study. Vol I. Final Technical Rept., Vol. II: Final Appendices. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2017-060. 1,000 + apps.

Day RH, Weingartner TJ, Hopcroft RR, Aerts LAM, Blanchard AL, Gall AE, Gallaway BJ, Hannay DE, Holladay BA, Mathis JT. 2013. The offshore northeastern Chukchi Sea, Alaska: a complex high-latitude ecosystem. Cont Shelf Res. 67:147-165.

Diaz RJ, Blake JA, Cutter GR Jr. 1994. Input, accumulation and cycling of materials on the continental slope off Cape Hatteras. Deep-Sea Res Pt II. 41(4-6): 707-982.

Donohue K, Hamilton P, Leven R, Watts R, Waddell E. 2008. Survey of deepwater currents in the northwestern Gulf of Mexico. Volume 1: Executive Summary. New Orleans (LA): U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. OCS Study 2008-030. 73 p.

Doyle MJ, Strom SL, Coyle KO, Hermann AJ, Ladd C, Matarese AC, Shotwell SK, Hopcroft RR. 2019. Early life history phenology among Gulf of Alaska fish species: strategies, synchronies, and sensitivities. Deep-Sea Res Pt II. In Press (Manuscript).

Duffy-Anderson JT, Blood DM, Cheng W, Ciannelli L, Matarese AC, Sohn D, Vance TC, Vestfals C. 2013. Combining field observations and modeling approaches to examine Greenland halibut (Reinhardtius hippoglossoides) early life ecology in the southeastern Bering Sea. J Sea Res. 75:96-109.

Dunn SC. 2016. Miocene contourite deposition (along-slope) near DeSoto Canyon, Gulf of Mexico: a product of an enhanced paleo-loop current [doctoral dissertation]. Tampa (FL): University of South Florida.

Eittreim S, Grantz A, Greenberg J. 1982. Active geologic processes in Barrow Canyon, northeast Chukchi Sea. Mar Geol. 50(1-2):61-76.

Embley B. 2010. Astoria Canyon: a natural laboratory. U.S. Department of Commerce, Office of Ocean Exploration and Research. [accessed 2019 Jun 27]. https://oceanexplorer.noaa.gov/explorations/lewis_clark01/background/geology/geology.html.

Felix DW, Gorsline DS. 1971. Newport submarine canyon, California: an example of the effects of shifting loci of sand supply upon canyon position. Mar Geol. 10(3):177-198.

Fiduk J, Weimer P, Trudgill B, Rowan M. 1999. The Perdido fold belt, northwestern deep Gulf of Mexico, part 2: seismic stratigraphy and petroleum systems. AAPG Bulletin. 83(4):578-612.

Fissel DB, Cross WE, Howland KL. 2013. An ecological and oceanographic assessment of the Beaufort Sea region: evaluation of the risks associated with ballast water exchange. Canadian Science Advisory Secretariat, Fisheries and Oceans Canada. Report No. Research Document 2012/149. 69 p.

Forde EB. 1981. Evolution of Veatch, Washington, and Norfolk submarine canyons: inferences from strata and morphology. Mar Geol. 39(3):197-214.

Gardner JV, Field ME, Twitchell DC. 2005. Geology of the U.S. seafloor: the view from Gloria. New York (NY): Cambridge University Press.

Garrison EG, Cook Hale J, Holland JL, Kelley AR, Kelley JT, Lowery D, Merwin DE, Robinson DS, Schaefer CA, Thomas BW, Thomas LA, Watts GP. 2012. Prehistoric site potential and historic shipwrecks on the Atlantic Outer Continental Shelf. Atlantic OCS Region: U.S. Department of the Interior, Bureau of Ocean Energy Management. 300 p.

Geological Survey of Canada. 1972. Report of activities, part A: April to October, 1971. Ottawa, Canada. Geological Survey of Canada. 260 p.

Goffredi SK, Morella NM, Pulcrano ME. 2012. Affiliations between bacteria and marine fish leeches (Piscicolidae), with emphasis on a deep-sea species from Monterey Canyon, CA. Environ Microbiol. 14(9):2429-2444.

Grantz A, Eittreim S. 1979. Geology and physiography of the continental margin north of Alaska and implications for the origin of the Canada basin. Menlo Park (CA): U.S. Department of the Interior, U.S. Geological Survey. Report No. USGS Open-File Report 79-288. 86 p.

Grebmeier JM, Overland JE, Moore SE, Farley EV, Carmack EC, Cooper LW, Frey KE, Helle JH, McLaughlin FA, McNutt SL. 2006. A major ecosystem shift in the northern Bering Sea. Science. 311(5766):1461-4.

Grow JA, Klitgord KD, Schlee JS. 1988. Structure and evolution of Baltimore Canyon Trough. In: Sheridan RE, Grow JA, editors. The Atlantic continental margin. Boulder (CO): Geol Soc Am. p. 269-290.

Gwiazda R, Paull CK, Caress DW, Lorenson T, Brewer PG, Peltzer ET, Walz PM, Anderson K, Lundsten E. 2016. Eel Canyon slump scar and associated fluid venting. In: Lamarche G, Mountjoy J, Bull S, Hubble T, Krastel S, Lane E, Micallef A, Moscardelli L, Mueller C, Pecher I, et al. Submarine mass movements and their consequences: 7th international symposium. Cham (CH): Springer International Publishing. p. 411-418.

Harris PT, Barrie JV, Conway KW, Greene HG. 2014. Hanging canyons of Haida Gwaii, British Columbia, Canada: fault-control on submarine canyon geomorphology along active continental margins. Deep-Sea Res Pt II. 104:83-92.

Hartwell SI. 2008. Distribution of DDT and other persistent organic contaminants in canyons and on the continental shelf off the central California coast. Mar Environ Res 65(3):199-217.

Hecker, B. 1993. Megafaunal assemblages. p. 75-120. In: Diaz RJ, Blake JA, Lohse DP, editors. Benthic study of the continental slope off Cape Hatteras, North Carolina. Volume II: Final Report. U.S. Department of the Interior, Minerals Management Service, OCS Study, MMS No. 30672 and 93-0015.

Hickey BM, Banas NES. 2008. Why is the northern California current so productive? Oceanography. 21(4):90-107.

Horowitz WL, Steffy DA, Hoose PJ. 1989. Geologic report for the Shumagin Planning Area, western Gulf of Alaska. Anchorage (AK): U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region. OCS Report MMS 89-0097. 155 p.

Hourigan TF. 2009. Managing fishery impacts on deep-water coral ecosystems of the USA: emerging best practices. Mar Ecol Prog Ser. 397:333-340.

Howell DG, Crouch JK, Greene HG, McCulloch DS, Vedder JG. 1980. Basin development along the late Mesozoic and Cainozoic California margin: a plate tectonic margin of subduction, oblique subduction, and transform tectonics. In: Redding HG, Ballence TF, editors. International Association of Sedimentologists Special Publication No. 4. pp. 43-62.

Hoyt J, Delgado JP, Barr BW, Terrell BG, Grussing V. 2014. Graveyard of the Atlantic, an overview of North Carolina's maritime cultural landscape. Silver Spring (MD): National Oceanic and Atmospheric Administration Office of National Marine Sanctuaries. 74 p.

Jochens AE, DiMarco SF, Nowlin WD Jr., Reid RO, Kennicutt MCI. 2002. Northeastern Gulf of Mexico chemical oceanography and hydrography study: synthesis report. New Orleans (LA): U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. Report No. OCS Study MMS 2002-055. 586 p.

Krivor MC, de Bry J, Linville NJ, Wells DJ. 2011. Archival investigations for Colonial Era shipwrecks in ultra-deepwater within the Gulf of Mexico. New Orleans (LA): U.S. Department of the Interior, BOEMRE, Gulf of Mexico OCS Region. OCS Study BOEMRE 2011-004. 166 p.

Kuenzel NA. 2011. Quantitative morphological analysis of submarine canyon-channel systems on the U.S. Atlantic continental margin [master's thesis]. Durham (NH): University of New Hampshire.

LaBrecque E, Curtice C, Harrison J, Van Parijs SM, Halpin PN. 2015. 3. Biologically important areas for cetaceans within U.S waters - Gulf of Mexico region. Aquat Mamm. 41(1):30-38.

Le Dantec N, Hogarth LJ, Driscoll NW, Babcock JM, Barnhardt WA, Schwab WC. 2010. Tectonic controls on nearshore sediment accumulation and submarine canyon morphology offshore La Jolla, Southern California. Mar Geol. 268(1):115-128.

Lee GH, Watkins JS, Bryant WR. 1992. Origin and evolution of Keathley Canyon, northwestern Gulf of Mexico. In: Watkins JS, Zhiqiang F, McMillen KJ, editors. Geology and geophysics of continental margins. Tulsa (OK): Am Assoc Pet Geol. p. 361-373.

Lentz SJ, Butman B, Harris C. 2014. The vertical structure of the circulation and dynamics in Hudson shelf valley. J Geophys Res Oceans 119, 3694-3713.

MacLean SA, Rooper CN, Sigler MF. 2017. Corals, canyons, and conservation: Science based fisheries management decisions in the eastern bering sea. Front Mar Sci. 4:142.

Maurer D, Robertson G, Gerlinger T. 1995. Community structure of soft-bottom macrobenthos of the Newport Submarine Canyon, California. Mar Ecol. 16(1):57-72.

McClain CR, Barry JP. 2010. Habitat heterogeneity, disturbance, and productivity work in concert to regulate biodiversity in deep submarine canyons. Ecology. 91(4):964-976.

McGregor BA. 1981. Ancestral head of Wilmington Canyon. Geology. 9(6):254-257.

Miller RJ, Hocevar J, Stone RP, Fedorov DV. 2012. Structure-forming corals and sponges and their use as fish habitat in Bering Sea submarine canyons. PLoS One. 7(3):e33885. Seeking the shore: evidence for active submarine canyon head incisi

Moors-Murphy HB. 2014. Submarine canyons as important habitat for cetaceans, with special reference to the Gully: A review. Deep-Sea Res Pt II. 104:6-19.

Mordy CW, Stabeno PJ, Kachel NB, Kachel D, Ladd C, Zimmermann M, Hermann AJ, Coyle KO, Doyle MJ. 2019. Patterns of flow in the canyons of the northern Gulf of Alaska. Deep-Sea Res Pt II.

[NEFMC] New England Fishery Management Council, [NMFS] National Marine Fisheries Service. 2017. Omnibus essential fish habitat amendment 2. Volume 2: EFH and HAPC designation alternatives and environmental impacts. Amendment 14 to the Northeast multispecies FMP. Amendment 14 to the Atlantic sea scallop FMP. Amendment 4 to the monkfish FMP. Amendment 3 to the Atlantic herring FMP. Amendment 2 to the red crab FMP. Amendment 2 to the skate FMP. Amendment 3 to the Atlantic salmon FMP. Newburyport (MA): New England Fishery Management Council. Report No. OHA2 FEIS - Volume 2. 143 p.

[NOAA] National Oceanic and Atmospheric Administration. 2016. 2016 Nautilus Expedition. U.S. Department of Commerce, Office of National Marine Sanctuaries. [accessed 2019 Jun 29]. https://sanctuaries.noaa.gov/science/nautilus16/.

[NOAA] National Oceanic and Atmospheric Administration. 2019. Wrecks and obstructions database. AWOIS and ENC. U.S. Department of Commerce, Office of Coast Survey; [accessed 2019 Jun 25]. https://nauticalcharts.noaa.gov/data/wrecks-and-obstructions.html.

Normark WR, Gutmacher CE. 1985. Chapter 10, Delgada Fan, Pacific Ocean. In: Bouma AH, Normark WR, Barnes NE, editors. Submarine fans and related turbidite systems. New York (NY): Springer-Verlag.

Normark WR, Carlson PR. 2003. Giant submarine canyons: is size any clue to their importance in the rock record? In: Chan MA, Archer AW, editors. Extreme depositional environments: mega end members in geologic time. Boulder (CO): Geol Soc Am. p. 175-190.

Nosal AP, Cartamil DC, Long JW, Lührmann M, Wegner NC, Graham JB. 2013. Demography and movement patterns of leopard sharks (Triakis semifasciata) aggregating near the head of a submarine canyon along the open coast of southern California, USA. Environ Biol Fish. 96(7):865-878.

Obelcz J, Brothers D, Chaytor J, Brink Ut, Ross SW, Brooke S. 2014. Geomorphic characterization of four shelf-sourced submarine canyons along the U.S. Mid-Atlantic continental margin. Deep-Sea Res Pt II. 104:106-119.

Paull C, McGann M, Sumner JE, Barnes P, Lundsten E, Anderson K, Gwiazda R, Edwards B, Caress D. 2014. Sub-decadal turbidite frequency during the early Holocene: Eel fan, offshore northern California. Geology 42:855-858.

Paull CK, Schlining B, Ussler W, Lundste E, Barry JP, Caress DW, Johnson JE, McGann M. 2010. Submarine mass transport within Monterey Canyon: benthic disturbance controls on the distribution of chemosynthetic biological communities. In: Mosher DC, Shipp RC, Moscardelli L, Chaytor JD, Baxter CDP, Lee HJ, Urgeles R, editors. Submarine mass movements and their consequences: 4th International Symposium. Dordrecht (NL): Springer International Publishing. p. 229-246.

Paull CK, Caress DW, Lundsten E, Gwiazda R, Anderson K, McGann M, Conrad J, Edwards B, Sumner EJ. 2013. Anatomy of the La Jolla submarine canyon system; offshore southern California. Mar Geol. 335:16-34.

Peterson WT, Morgan CA, Fisher JP, Casillas E. 2010. Ocean distribution and habitat associations of yearling coho (Oncorhynchus kisutch) and Chinook (O. tshawytscha) salmon in the northern California Current. Fish Oceanogr. 19(6):508-525.

Piatt JF, Wetzel J, Bell K, DeGange AR, Balogh GR, Drew SD, Geernaert T, Ladd C, Byrd GV. 2006. Predictable hotspots and foraging habitat of the endangered short-tailed albatross (Phoebastria albatrus) in the North Pacific: implications for conservation. Deep-Sea Res Pt I. 53(3-4)387-398.

Pierdomenico M, Gori A, Guida VG, Gili J-M. 2017. Megabenthic assemblages at the Hudson Canyon head (NW Atlantic margin): habitat-faunal relationships. Prog Oceanogr. 157:12-26.

Prouty NG, Sahy D, Ruppel CD, Roark EB, Condon D, Brooke S, Ross SW, Demopoulos AWJ. 2016. Insights into methane dynamics from analysis of authigenic carbonates and chemosynthetic mussels at newly-discovered Atlantic margin seeps. Earth Planet Sci Lett. 449:332-344.

Puig P, Ogston AS, Mullenbach BL, Nittrouer CA, Sternberg RW. 2003. Shelf-to-canyon sediment-transport processes on the Eel continental margin (northern California). Mar Geol. 193:129-149.

Quattrini AM, Nizinski MS, Chaytor JD, Demopoulos AWJ, Roark EB, France SC, Moore JA, Heyl T, Auster PJ, Kinlan B, et al. 2015. Exploration of the canyon-incised continental margin of the northeastern United States reveals dynamic habitats and diverse communities. PLoS One. 10(10):e0139904-e0139904.

Raineault NA, Flanders J, Bowman A. 2018. New frontiers in ocean exploration; The E/V Nautilus, Ship Okeanos Explorer, and R/V Falkor 2017 field season. Oceanography. 31(1, Supplement):126.

Roberts HH, Fisher CR, Brooks JM, Bernard B, Carney RS, Cordes E, Shedd W, Hunt J Jr, Joye S, MacDonald IR et al. 2007. Exploration of the deep Gulf of Mexico slope using DSV Alvin: site selection and geologic character. GCAGS Transactions. (57):647-659.

Roletto J, Brennan ML, Williams G, Piotrowski C, Cochrane G, Delgado JP, Wagner J Marranzino A, Schwemmer RV. 2016. Mapping and exploration of deep-sea corals and shipwrecks in the Greater Farallones National Marine Sanctuary. In: Bell KLC, Flanders J, Bowman A, Raineault NA, editors. 2016. New frontiers in ocean exploration: the E/V Nautilus, NOAA Ship Okeanos Explorer, and R/V Falkor 2016 field season. Oceanography. 30(1):32-33.

Romans B. 2011. Seafloor Sunday #81: Hueneme submarine canyon, California. [accessed 2019 Jun 29]. https://www.wired.com/2011/01/seafloor-sunday-81-hueneme-submarine-canyon-california/.

Rooper CN, Stone RP, Etnoyer P, Conrath C, Reynolds J, Greene HG, Williams B, Salgado E, Morrison C, Waller R, et al. 2017. Deep-sea coral research and technology program: Alaska deep-sea coral and sponge initiative final report. Silver Spring (MD): U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Service NMF. NOAA Technical Memorandum NMFS-OHC-2. 65 p.

Ross CB, Gardner WD, Richardson MJ, Asper VL. 2009. Currents and sediment transport in the Mississippi Canyon and effects of Hurricane Georges. Cont Shelf Res. 29(11):1384-1396.

Ross SW, Rhode M, Quattrini AM. 2015. Demersal fish distribution and habitat use within and near Baltimore and Norfolk Canyons, U.S. middle Atlantic slope. Deep-Sea Res Pt I. 103:137-154.

Ryan JP, McManus MA, Sullivan JM. 2010. Interacting physical, chemical and biological forcing of phytoplankton thin-layer variability in Monterey Bay, California. Cont Shelf Res. 30(1):7-16.

Santora JA, Field JC, Schroeder ID, Sakuma KM, Wells BK, Sydeman WJ. 2012. Spatial ecology of krill, micronekton and top predators in the central California Current: implications for defining ecologically important areas. Prog Oceanogr. 106, 154-174.

Santora JA, Zeno R, Dorman JG, Sydeman WJ. 2018. Submarine canyons represent an essential habitat network for krill hotspots in a large marine ecosystem. Sci Rep. 8(1):7579.

Schaff T, Levin L, Blair N, DeMaster D, Pope R, Boehme S. 1992. Spatial heterogeneity of benthos on the Carolina continental slope: large (100 km)-scale variation. Mar Ecol Prog Ser. 88:143-160.

Schlining K, von Thun S, Kuhnz L, Schlining B, Lundsten L, Jacobsen Stout N, Chaney L, Connor J. 2013. Debris in the deep: using a 22-year video annotation database to survey marine litter in Monterey Canyon, central California, USA. Deep-Sea Res Pt I. 79:96-105.

Shroyer EL. 2012. Turbulent kinetic energy dissipation in Barrow Canyon. J Phys Oceanogr. 42(6):1012-1021.

Sigler MF, Rooper CN, Hoff GR, Stone RP, McConnaughey RA, Wilderbuer TK. 2015. Faunal features of submarine canyons on the eastern Bering Sea slope. Mar Ecol Prog Ser. 526:21-40.

[SIMoN] Sanctuary Integrated Monitoring Network. n.d. Submarine canyons. [accessed 2019 Jun 29]. https://sanctuarysimon.org/monterey-bay-nms/submarine-canyons/.

Smith ME, Werner SH, Buscombe D, Finnegan NJ, Sumner EJ, Mueller ER. 2018. on due to coarse sediment supply and focusing of wave energy. Geophys Res Lett. 45:12,403-12,413.

Sulak KJ, Ross SW. 1996. Lilliputian bottom fish fauna of the Hatteras upper middle continental slope. J Fish Biol. 49:91-113.

Symons WO, Sumner EJ, Paull CK, Cartigny MJB, Xu JP, Maier KL, Lorenson TD, Talling PJ. 2017. A new model for turbidity current behavior based on integration of flow monitoring and precision coring in a submarine canyon. Geology. 45(4):367-370.

Tagart JV. 1997. Chapter 2: groundfish data collection in Washington. In: Sampson DB, Crone PR, editors. Commercial fisheries data collection procedures for U.S. Pacific coast groundfish. Newport (OR): National Oceanic and Atmospheric Administration. NOAA Tech Memo NMRS-NWFSC-31. p. 10.

Tucholke BE. 1987. Submarine geology. In: Milliman JD, Wright WR, editors. The marine environment of the U.S. Atlantic continental slope and rise. Boston (MA): Jones and Bartlett Publ, Inc. p. 56-113.

Van Pelt T. 2015. The Bering Sea project: understanding ecosystem processes in the Bering Sea. Seattle (WA): Bering Sea Project.

Vetter EW, Dayton PK. 1998. Macrofaunal communities within and adjacent to a detritus-rich submarine canyon. Deep-Sea Res Pt II. 45: 25–54.

Vetter EW, Dayton PK. 1999. Organic enrichment by macrophyte detritus, and abundance patterns of megafaunal populations in submarine canyons. Mar Ecol Prog Ser. 186:137–148.

von Thun S. 2013. Eel Canyon scour. Monterey Bay Aquarium Research Institute. [accessed 2019 Jun 27]. https://www.mbari.org/northern-2013-jul-30/.

Waring GT, Josephson E, Maze-Foley K, Rosel PE. 2016. U.S. Atlantic and Gulf of Mexico marine mammal stock assessments – 2015. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. NOAA Technical Memorandum NMFS NE 238.

Wei CL, Rowe GT, Hubbard GF, Scheltema AH, Wilson GDF, Petrescu I, Foster JM, Wicksten MK, Chen M, Davenport R, et al. 2010. Bathymetric zonation of deep-sea macrofauna in relation to export of surface phytoplankton production. Mar Ecol Prog Ser. 399:1-14.

Wei CL, Rowe GT, Haedrich RL, Boland GS. 2012. Long-term observations of epibenthic fish zonation in the deep northern Gulf of Mexico. PLoS One. 7(10):e46707.

Whittaker L. 2019. The reel deal: world-class fishing awaits aboard local charters. Opportunities abound in Clastop and Pacific counties. Our Coast Magazine. [accessed 2019 Jun 27]. https://www.discoverourcoast.com/our-coast-magazine/do-see/the-reel-deal-world-class-fishing-awaits-aboard-local-charters/article_7ce32ea8-12b7-11e9-aa6c-ef3ed9145533.html.

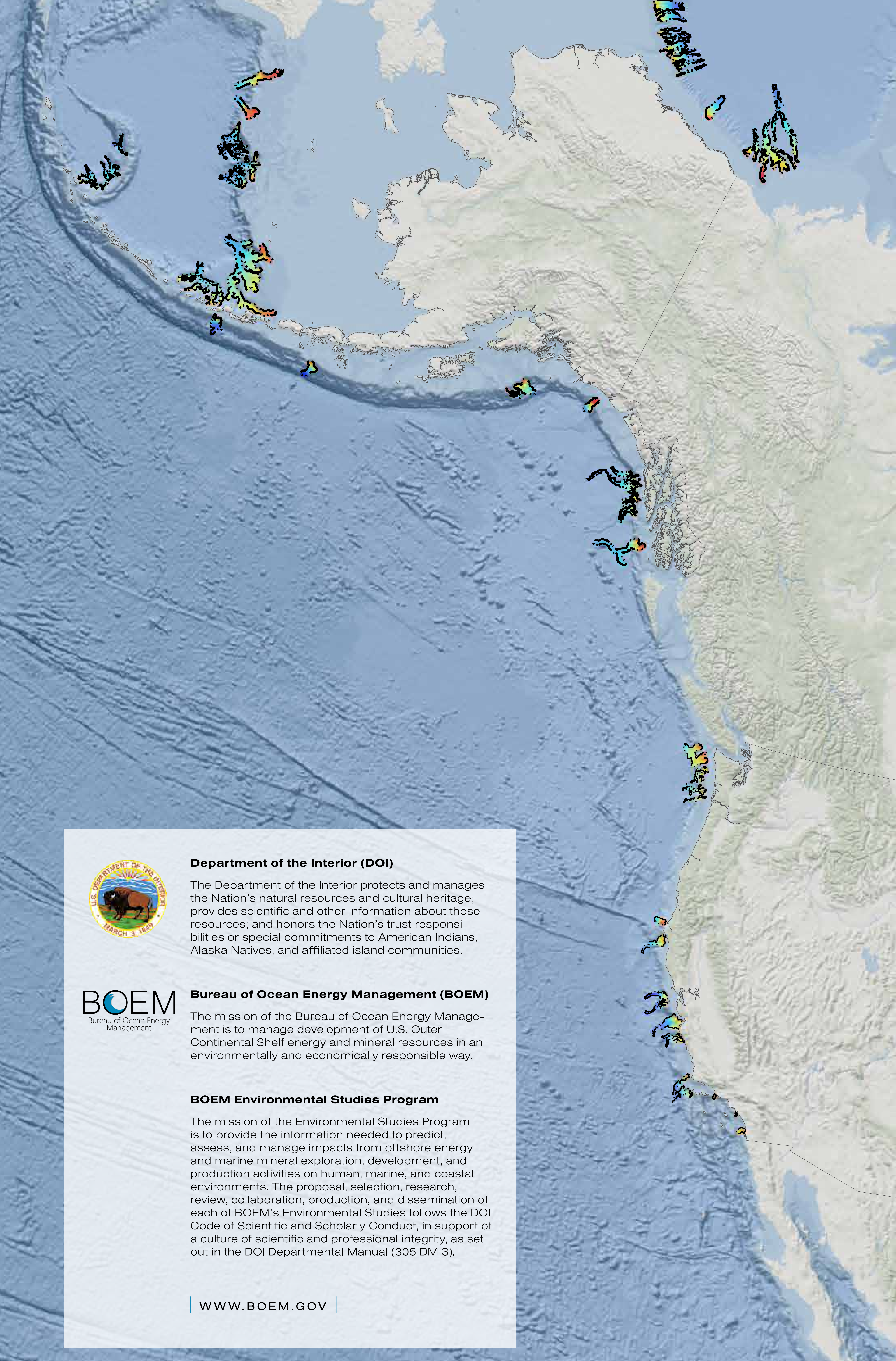
Wilde P. 1965. Recent sediments of the Monterey deep-sea fan. University of California Hydraulic Engineering Laboratory Submitted under Contract DA-49-055-CIV-ENG-63-4 with the Coastal Engineering Research Center. U.S. Army Technical Report No. HEL-2-13.

Wiley TJ. 1986. Sedimentary basins of offshore Alaska and adjacent regions. Menlo Park (CA): U.S. Department of the Interior, U.S. Geological Survey. USGS Open-File Report 86-35. 82 p.

Xu JP. 2010. Normalized velocity profiles of field-measured turbidity currents. Geology. 38(6):563-566.

Xu JP, Swarzenski PW, Noble M, Li A-C. 2010. Event-driven sediment flux in hueneme and mugu submarine canyons, southern california. Mar Geol. 269(1):74-88.

Zimmermann M, Prescott M. 2018. Bathymetry and canyons of the eastern Bering Sea slope. Geosciences. 8(5):184.



Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).

WWW.BOEM.GOV