Applications of Marine Vehicles

Prof. Nikola Mišković

http://impact.uni-bremen.de/

Goal

- get familiarized with application of marine vehicles in areas of:
  - **maritime security** - underwater UXOs
  - **marine ecology/biology**
    - oil spill detection
    - underwater habitat mapping (Posidonia oceanica)
  - **marine archaeology**
  - **deep sea mining**







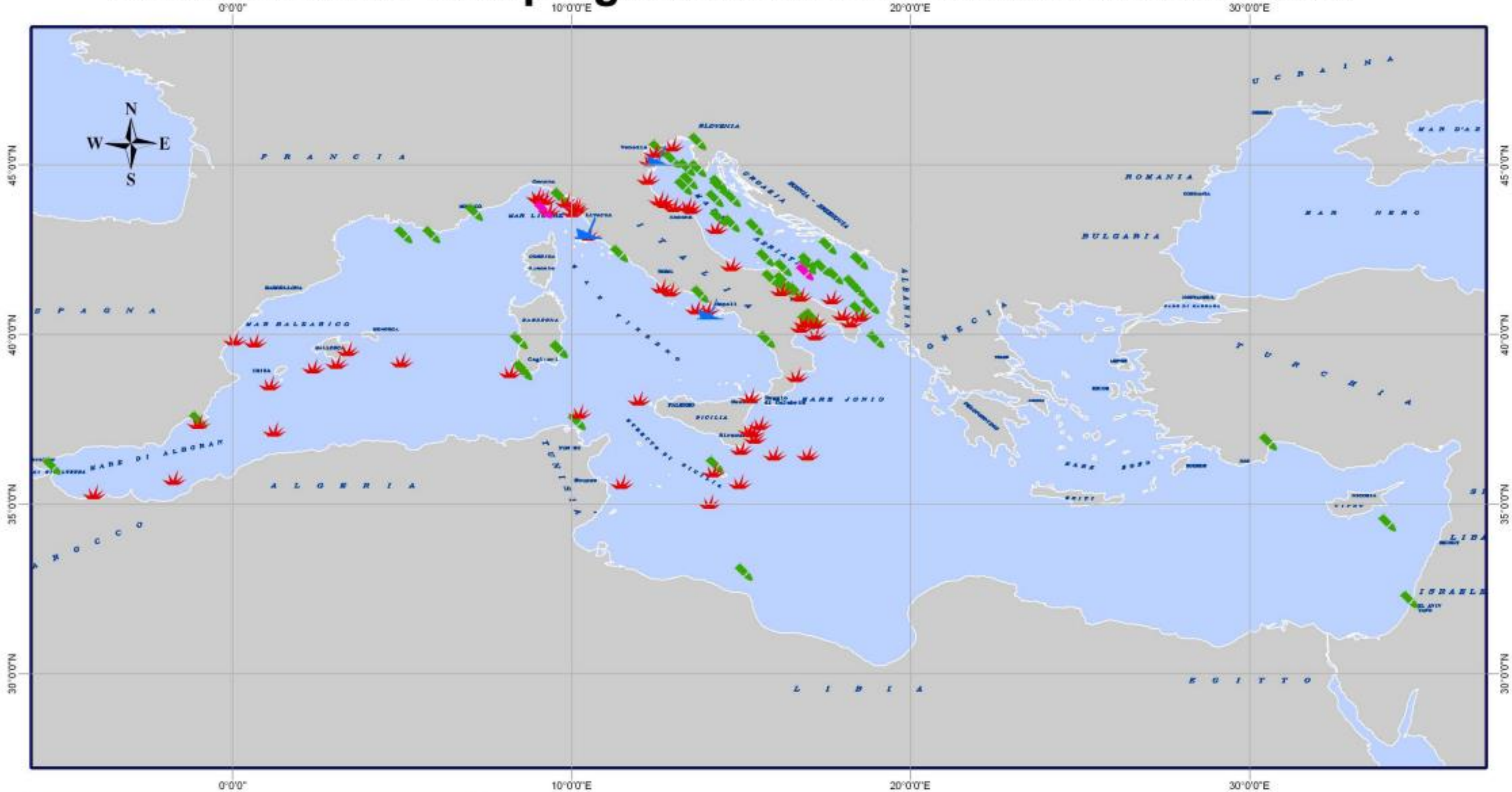


Aerial bomb
Torpedo
Aerial bomb
Naval mine
Naval mine
Projectile
Ammunition
Naval mine

Maritime Security

Underwater UXOs

Ammunitions dumping sites into the Mediterranean Sea



Legend

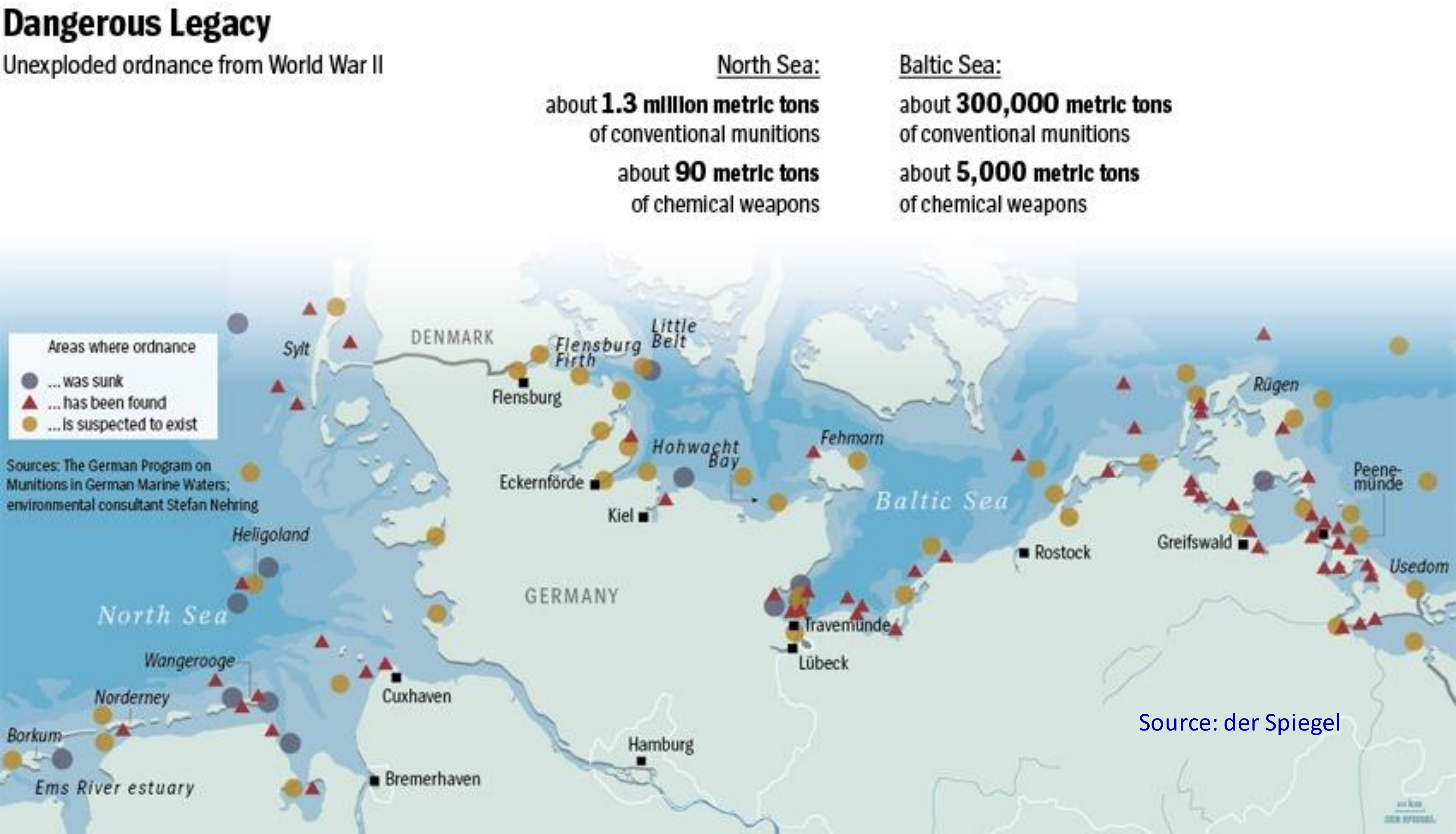
- *Shipwreck with ammunitions*
- *Firing Practice Area*
- *Chemical Weapons Dumping Area*
- *Ordance Dumping Area*
- *200 m*

Locations are mapped according with the data gathered from pilot books, nautical charts and specific studies

Map produced by the MEDU Secretariat in June 2008

by E. Amato, L. Alcaro, P. Giordano

...in the North Sea and the Baltic Sea



Source: der Spiegel

UXO in the Adriatic

torpedo	8 pieces
large airplane bombs	5 pieces
small and mid airplane bombs	153 pieces
mines	26 pieces
other projectiles and similar	250 pieces
grenades call. 430 mm	2 pieces
grenades and other projectiles	~14 tons
NC (topnički) barut	~35 tons

Gross weight of unexploded ordnance is in total around 147.250 kg with 51.400 kg of volatile explosives.

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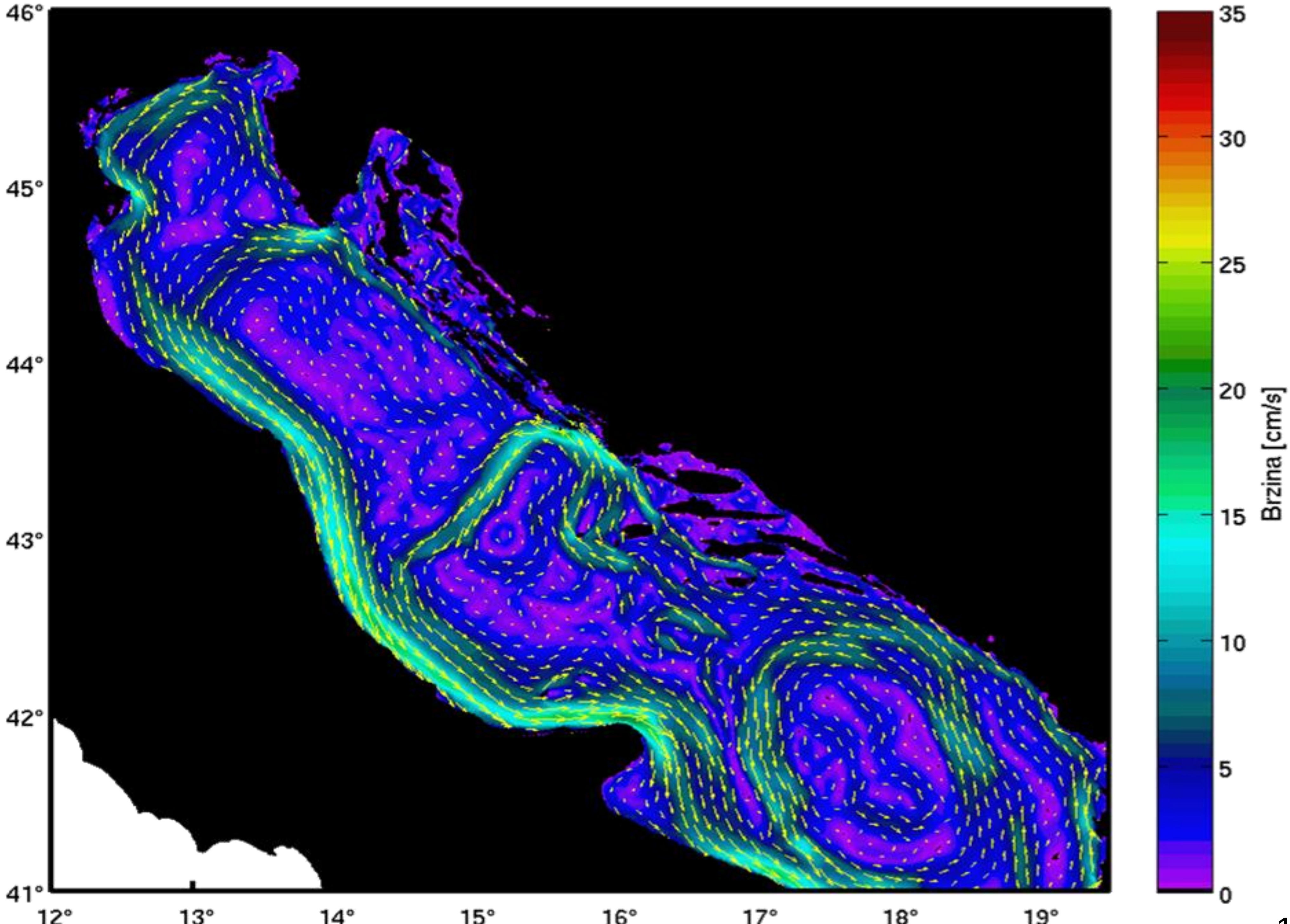
Mine operations in World War II

Area near the City of Bari, Italy



46°
45°
44°
43°
42°
41°
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14°
15°
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18°
19°
35
30
25
20
15
10
5
0
Brzina [cm/s]

Mustard gas, Yperite

- tactical weapon during WWI
- first use in 1916 in Ypres, Belgium
- ~1.2M people exposed during WWI - 100-120,000 fatalities.
- not use during WWII although large quantities of chemical weapons were available on both sides
- mustard gas leak after bombing of U.S. Liberty Ship John Harvey in Bari port, Italija; 600+ injured with 83 fatalities.
- evidence of mustard gas production in Syria, 2013

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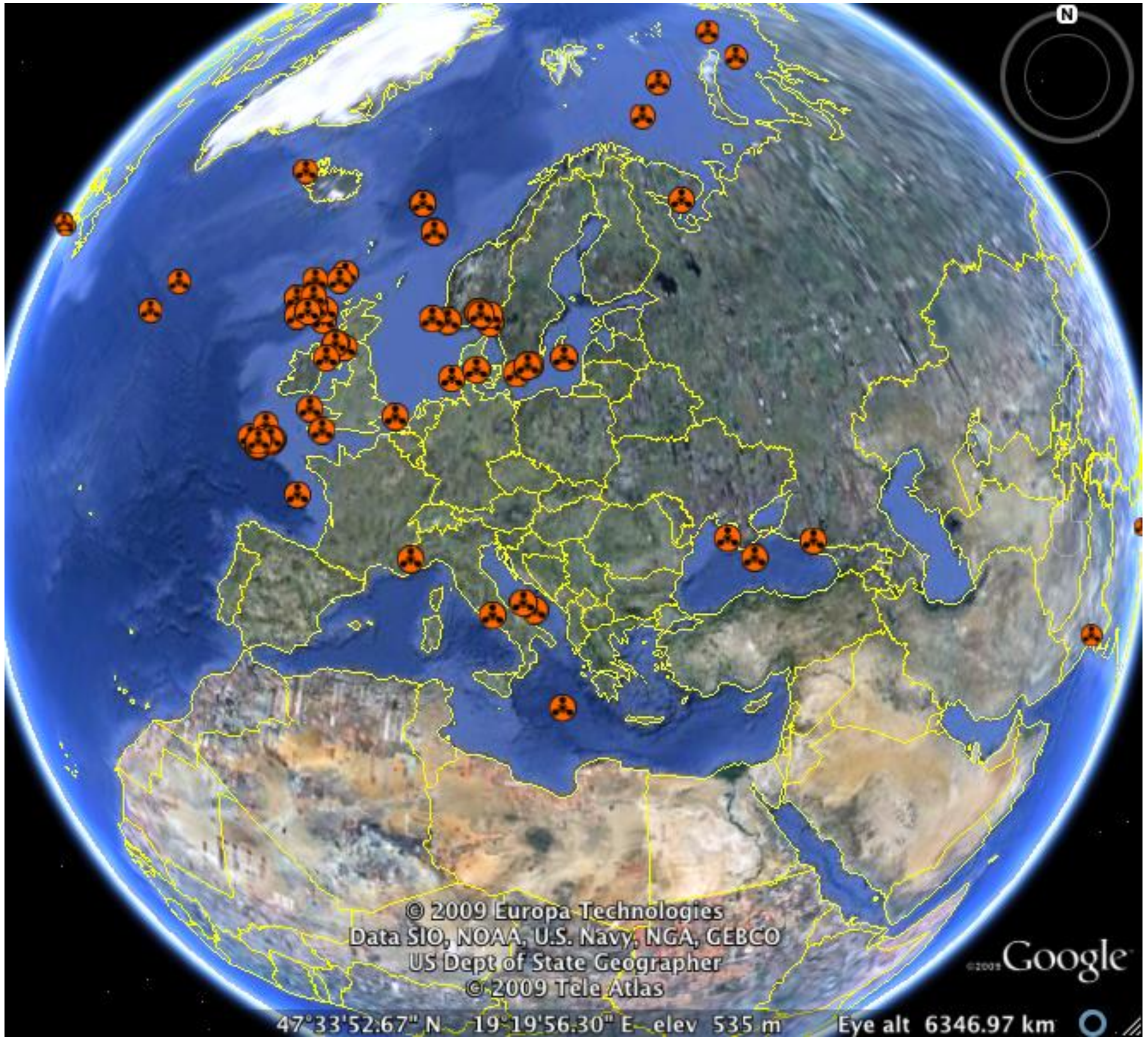
Bari - Harbor, Italy – 1943.

- One of the destroyed vessels, the US Liberty ship *John Harvey*, has been carrying a secret cargo of 2,000 M47A1 World War I type mustard gas bombs, each of them held 30-35kg (60-70 lb) of sulfur mustard.
- This cargo had been sent to Europe to retaliate if Germany resorted to chemical warfare

• The *John Harvey* was still waiting to unload on December 2, 1943. Since secrecy was paramount and few people knew of the mustard gas on board, the *John Harvey* **was not given priority to unload its cargo of mustard bombs**

• The German attack on Bari began at 7:20 in the evening on December 2, 1943

Neurotoxin sites



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Aerial bomb


Torpedo


Aerial bomb


Naval mine


Naval mine

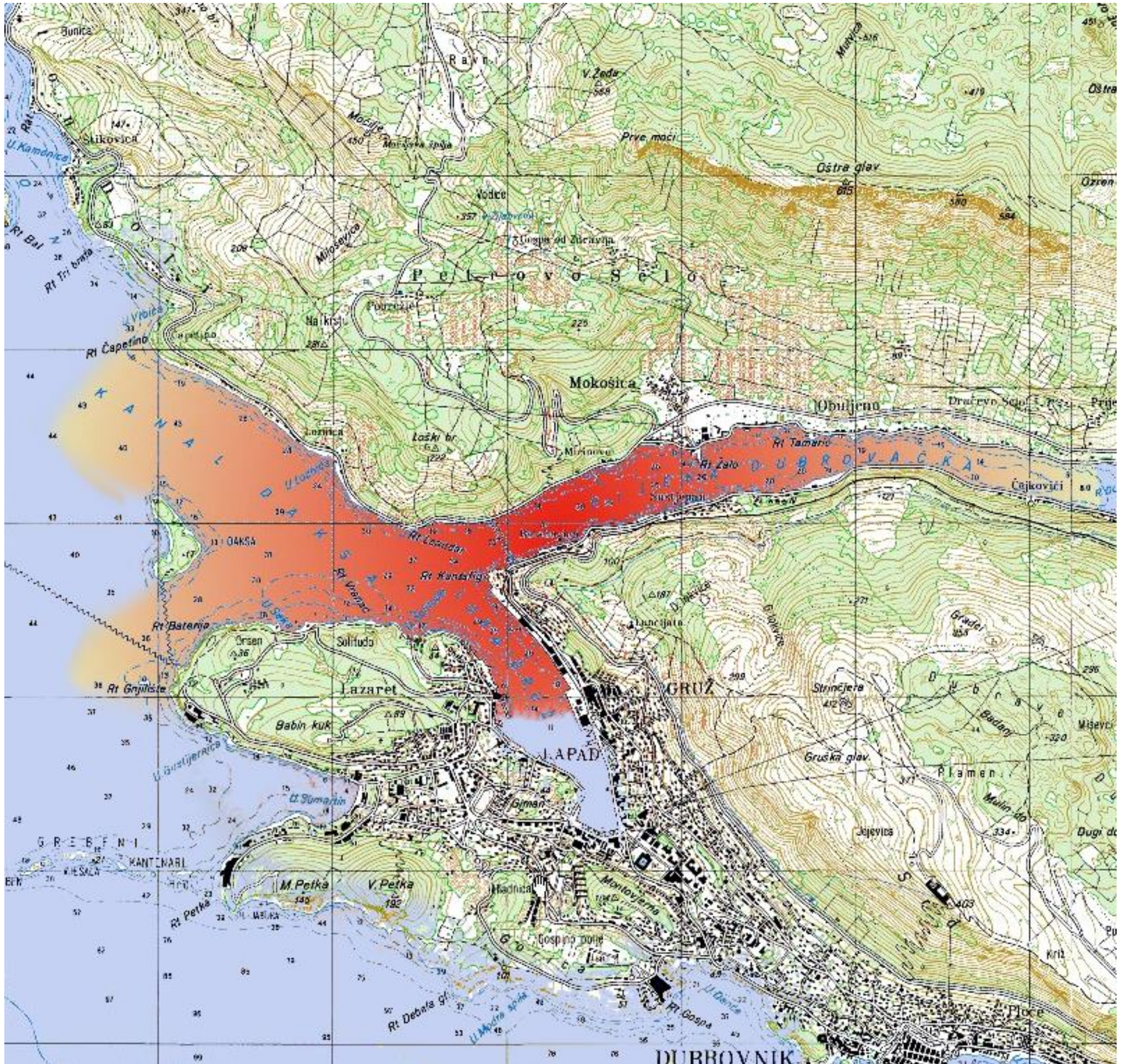

Projectile


Ammunition


Naval mine

Classical UXO neutralization method - Detonation

Explosion of 250 kg TNT – Danger Area



Ship mine on sea-bottom (LMB III)

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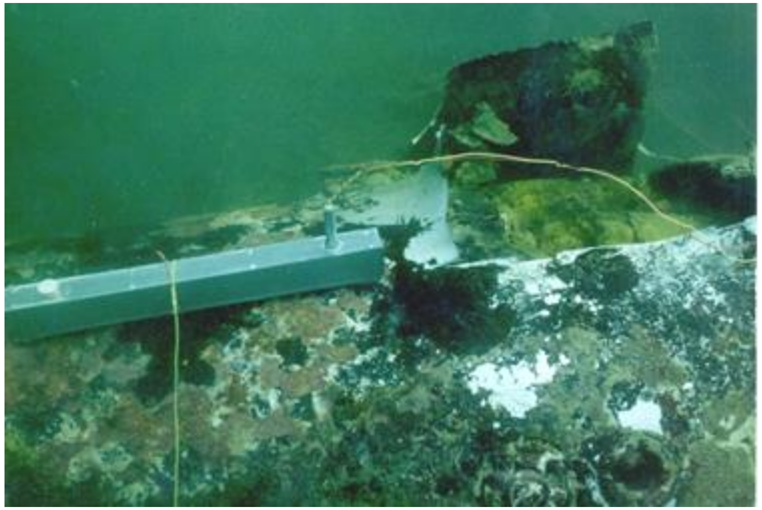
Recovery and transfer



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University of Zagreb

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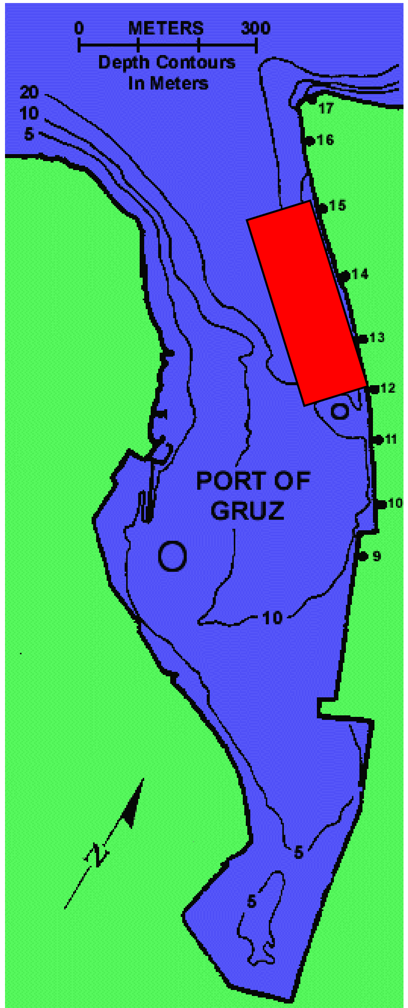
TÉCNICO LISBOA


Dubrovnik
Image © 2005 DigitalGlobe
Google
Pointer 42°38'29.02" N 18°04'12.44" E elev 9 ft
Streaming |||||||||| 100%
Eye alt 18415 ft

Port of Gruž (Dubrovnik) – UXO mission

Number of berthings in 2013 was 553 in 2014 438

Port of Gruž (Dubrovnik) – UXO mission in October, 2005



We were subcontracted for the inspection by the company „Major & Partners" in 2005
Area to be cleaned from UXO: ~32000 m²

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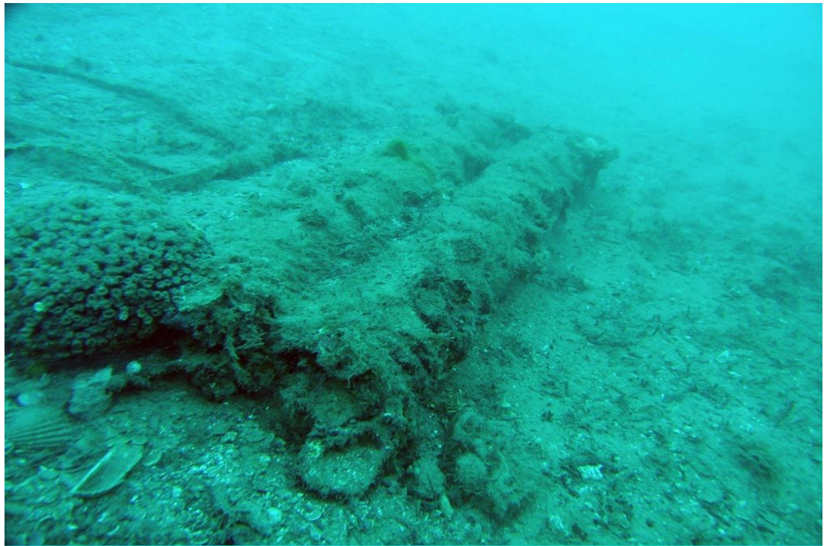
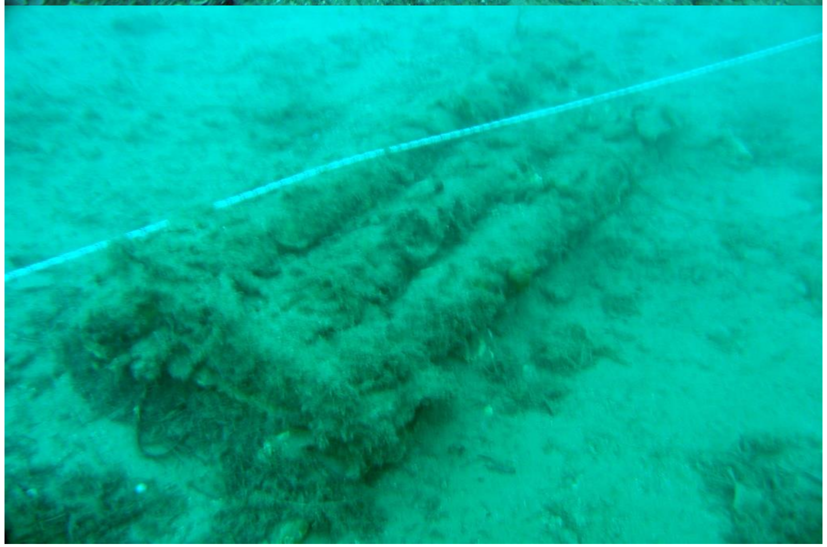
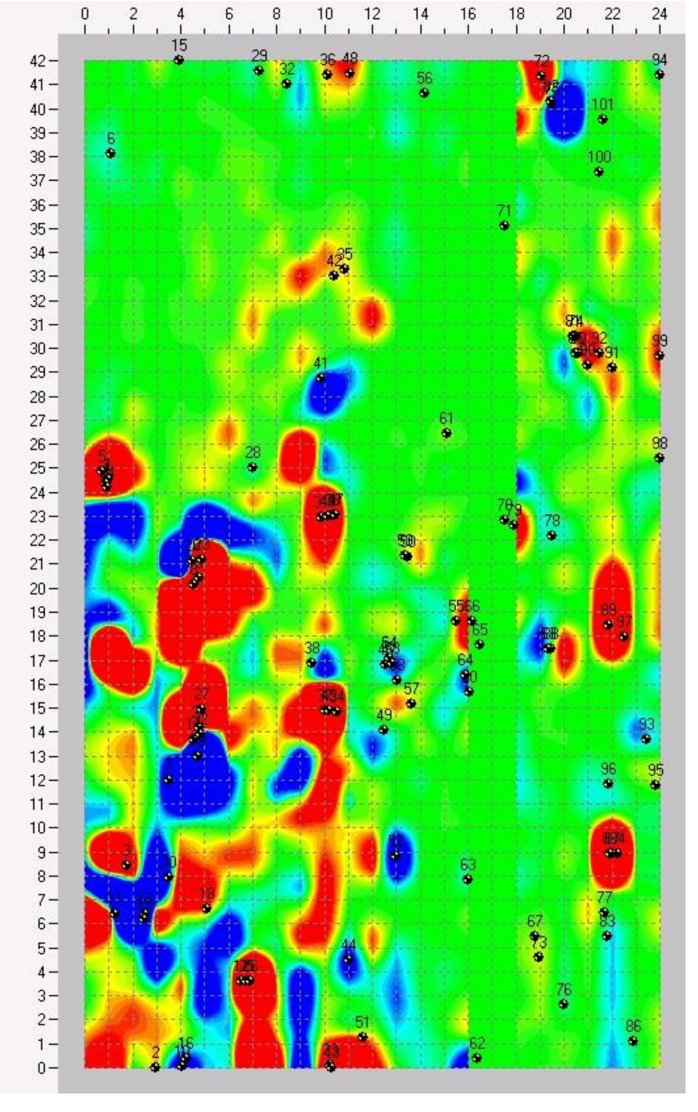
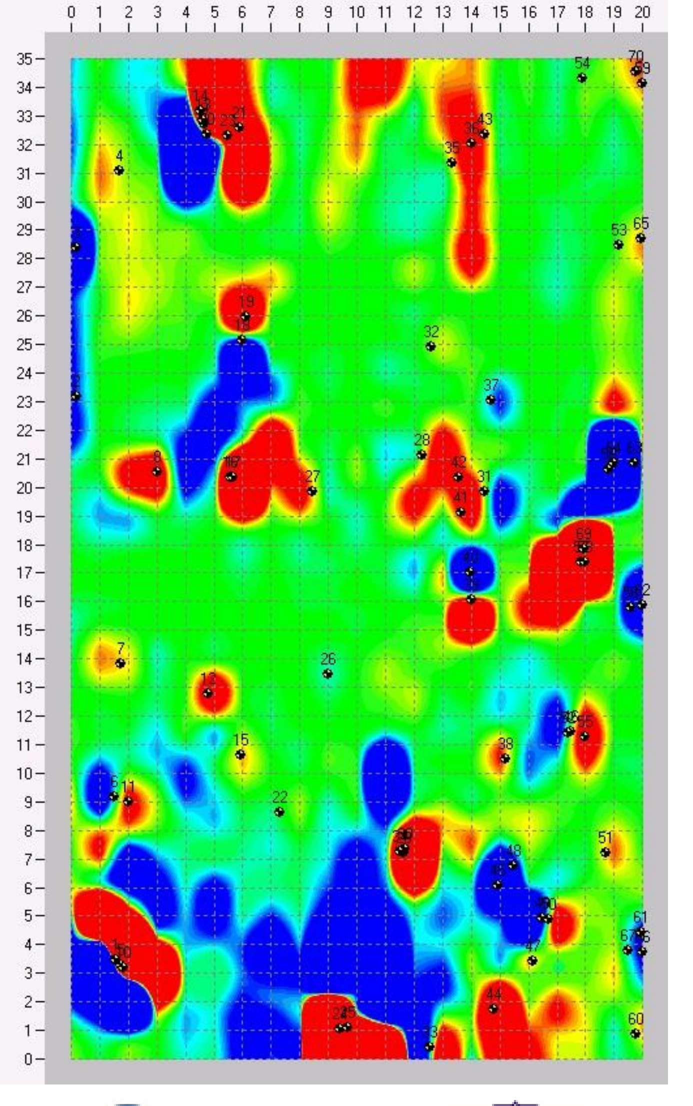
FINDINGS on the bottom





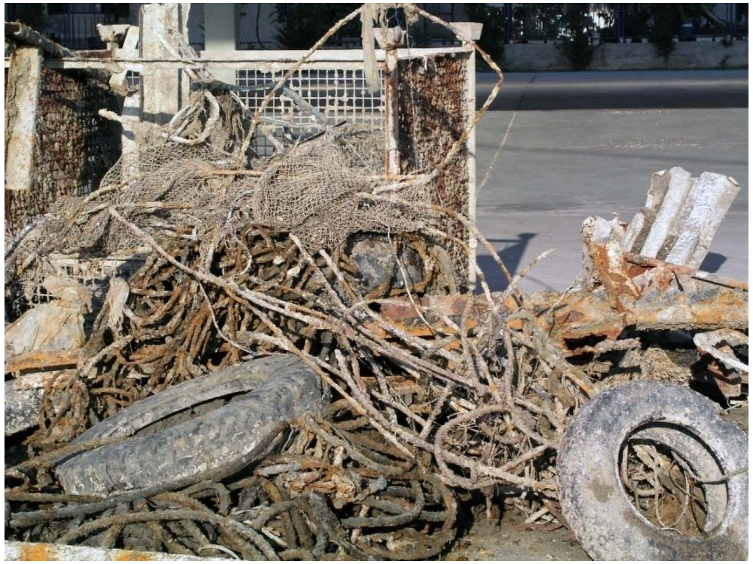
Bottom scanning
magnetic detector VALLON 1303D





Part of retrieved UXO in port of Gruž (Dubrovnik)

Part of retrieved garbage above UXO



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	Br.	Type of UXO	Quantity	Average ex. (kg)	Total explosive (kg)	Average mass (kg)	Total mass (kg)
	1	Ammunition cal 14,5 mm	110	0,002	0,165	0,026	2,860
	2	Cannon ammunition call 20 mm	4.912	0,017	83,504	0,205	1.006,960
	3	Cannon ammunition call 37 mm	5	0,034	0,170	1,460	7,300
	4	Cannon ammunition call 40 mm	2	0,080	0,160	2,154	4,308
	5	Cannon ammunition call 57 mm	10	0,753	7,530	6,600	66,000
	6	Cannon ammunition call 75 mm	1	1,350	1,350	8,300	8,300
	7	Cannon ammunition call 80 mm	1	0,900	0,900	12,000	12,000
	8	Cannon ammunition call 88 mm	17	2,700	45,900	19,500	331,500
	9	Cannon ammunition call 88 mm	2	0,900	1,800	7,200	14,400
	10	Airplane bombs 100	1	47,000	47,000	98,000	98,000
	11	Hand granades M (75,91,92,93)	1	0,040	0,040	0,355	0,355
		count	5.062	kg	188,5	gross kg	1.552,0

New cruiser berths in port of Gruž (Dubrovnik)

Project value: 24 mil.€
Project size: 850 m of new port line
Project period: 2006 - 2009
Investor: The Dubrovnik Port Authority

Autonomous Naval MCM Neutralization System

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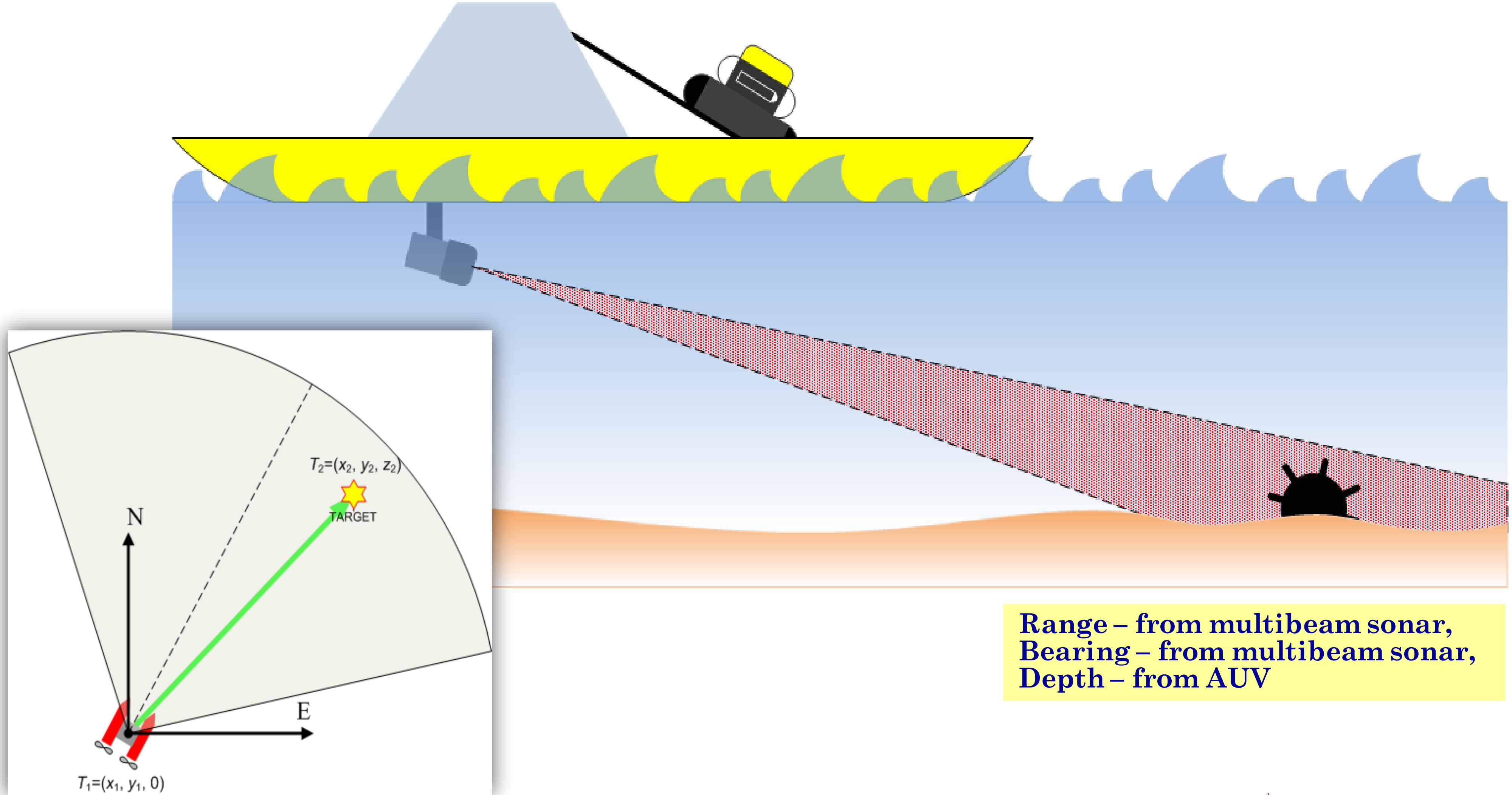
Autonomous Naval MCM Neutralization System



Range – from multibeam sonar,
Bearing – from multibeam sonar,
Depth – from AUV

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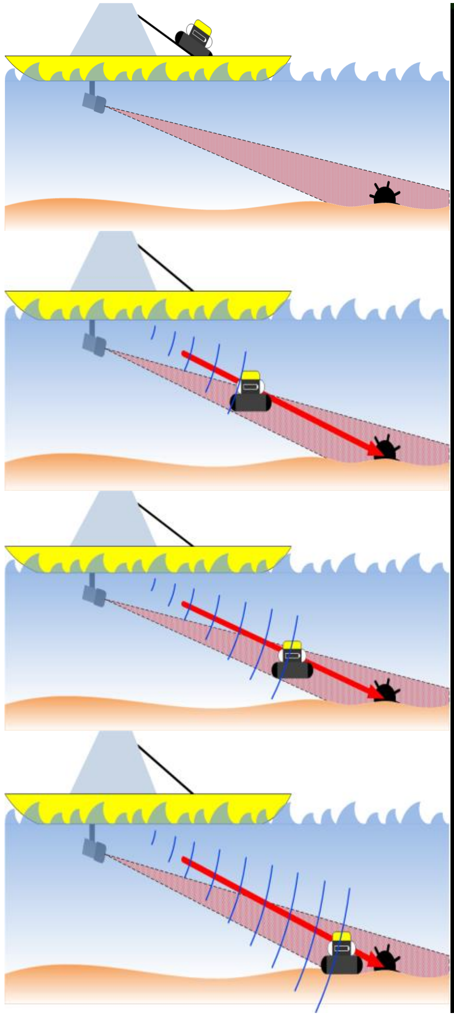
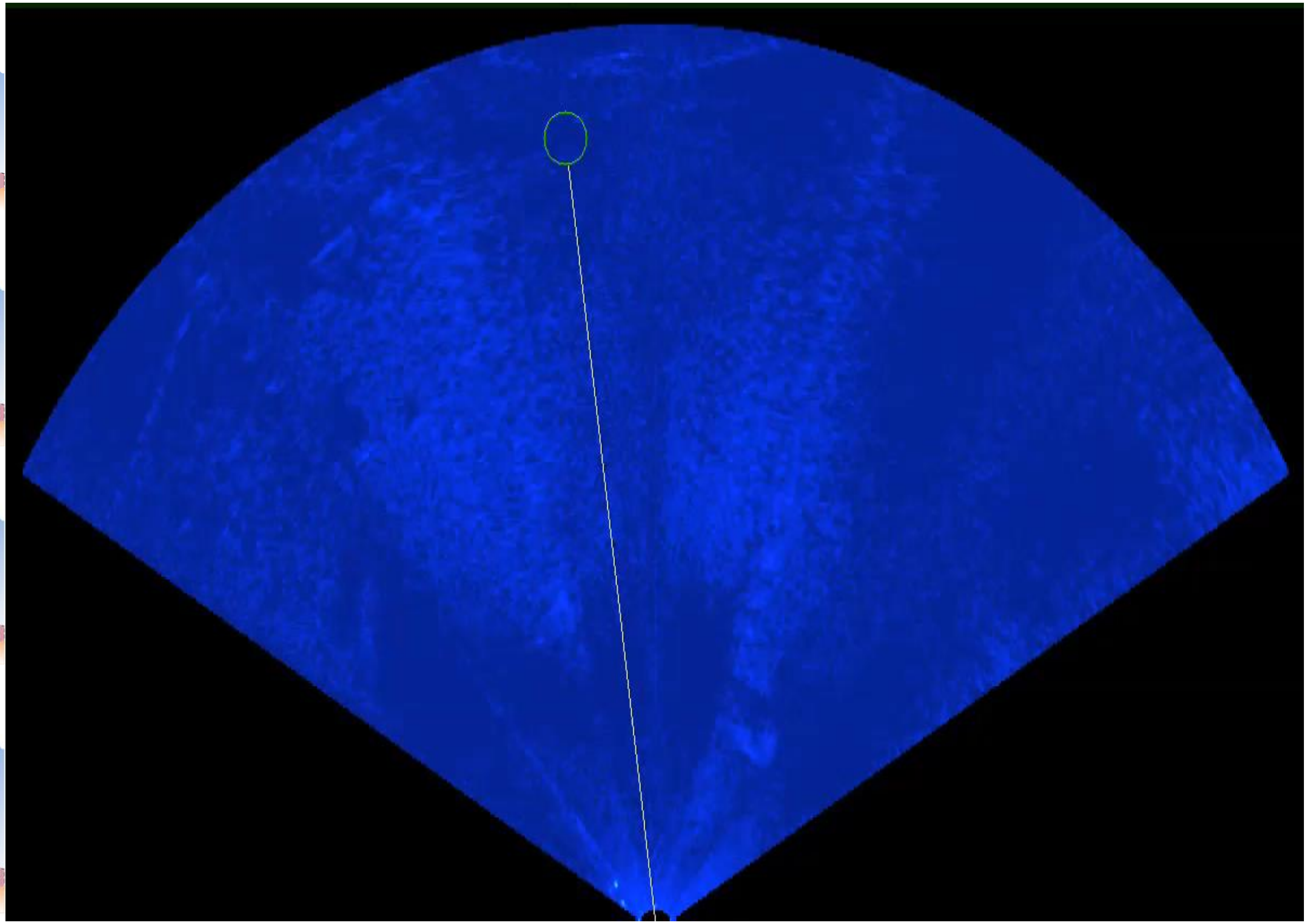
Autonomous MCM experiment





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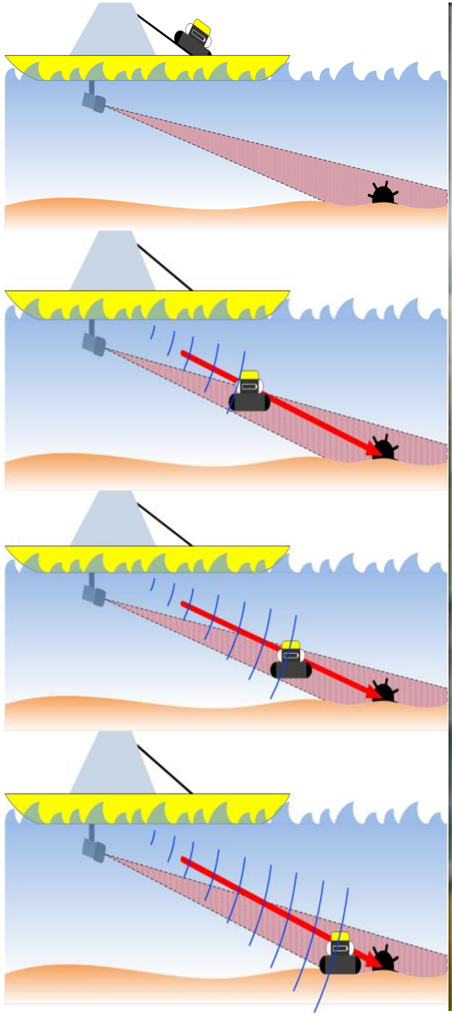
Video recording of experiment



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Marine Biology

Oil Spill Detection

Motivation

- The increased public interest in counter-measures for sub-surface releases of hydrocarbons
- **The Deepwater Horizon accident** in the Gulf of Mexico, 2010
  - began on April 20, 2010, in the Gulf of Mexico on the BP-operated Macondo Prospect
  - considered to be the largest marine oil spill in the history of the petroleum industry
  - estimated the total discharge at 4.9 million barrels (210 million US gal; 780,000 m3)
  - the well was declared sealed on September 19, 2010. Reports in early 2012 indicated that the well site was still leaking. The Deepwater Horizon oil spill is regarded as one of the largest environmental disasters in American history.
  - https://upload.wikimedia.org/wikipedia/commons/transcoded/f/f7/Deepwater_Horizon_fire_seen_by_US_Coast_Guard_helicopter.ogv/Deepwater_Horizon_fire_seen_by_US_Coast_Guard_helicopter.ogv.480p.vp9.webm
  - https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

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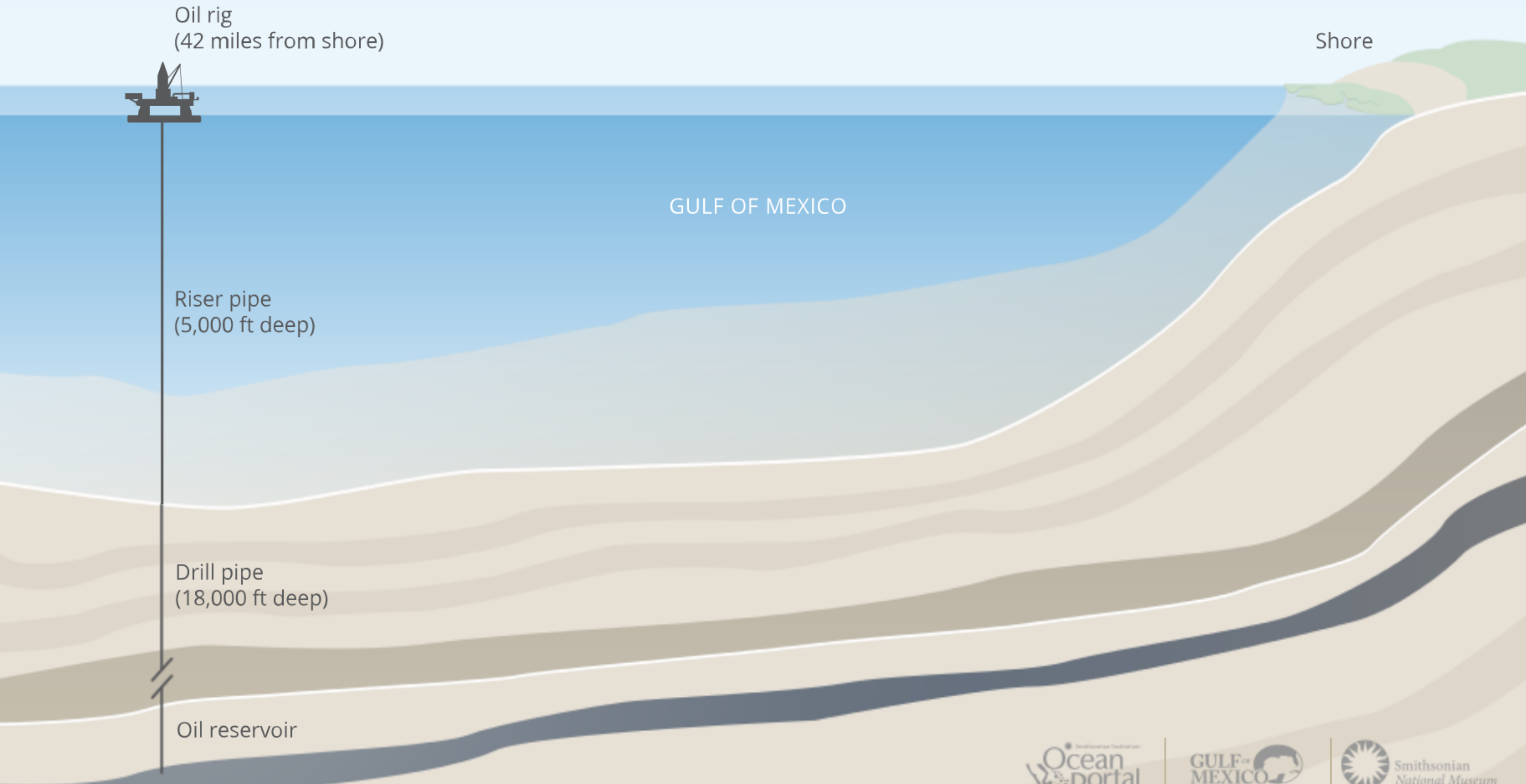
ANATOMY OF AN OIL SPILL:
SCIENCE FROM THE GULF OF MEXICO

Click on the buttons above to follow the path of the oil

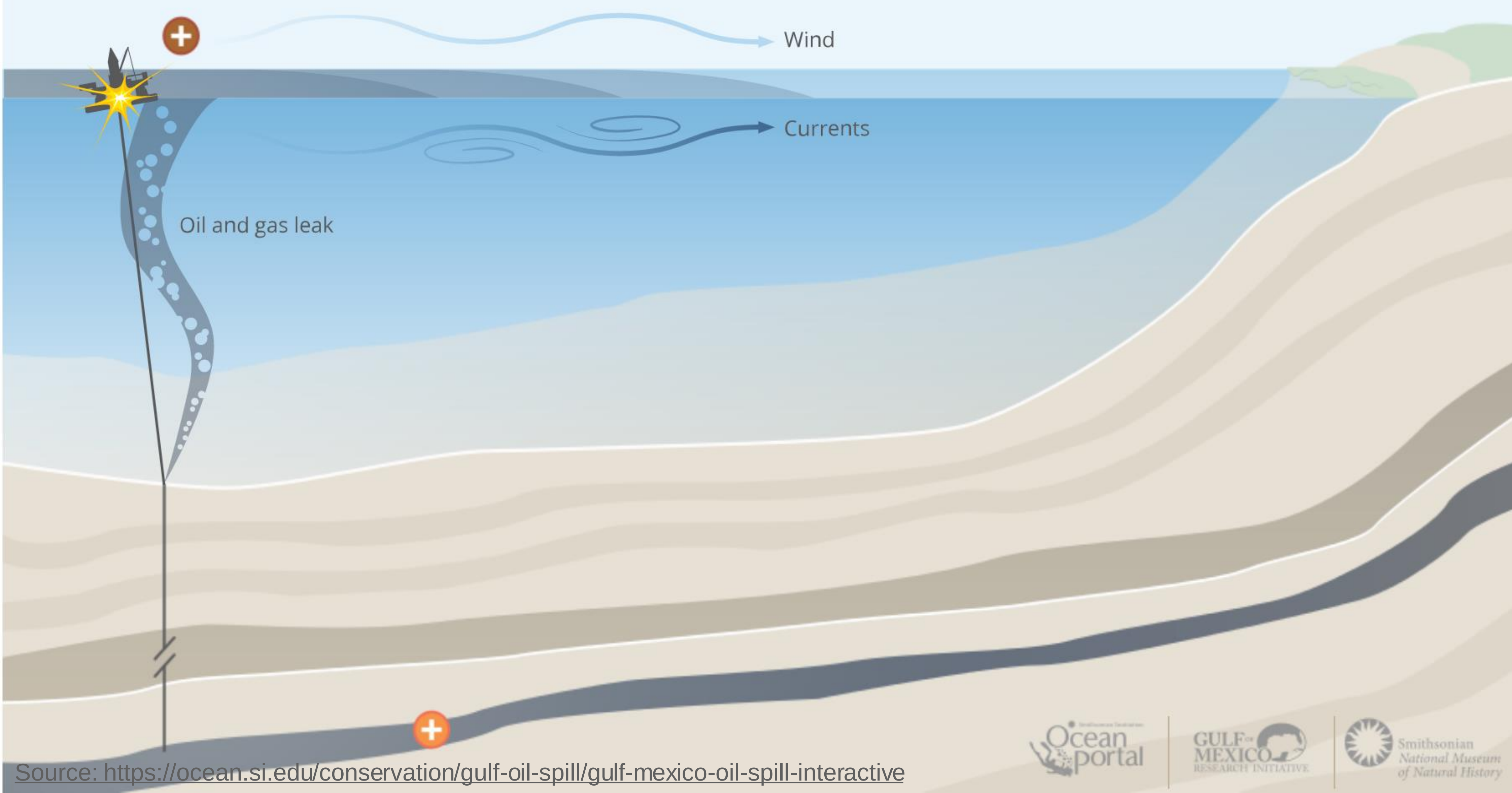
On April 20, 2010, the *Deepwater Horizon* oil rig exploded, killing eleven people and setting off the largest marine oil spill in world history. A few days later, underwater cameras revealed that oil and gas were leaking from the ocean floor about 42 miles off the coast of Louisiana. The oil well leaked 4.9 million barrels of oil before it was capped nearly 3 months later on July 15, 2010.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

THE DISASTER

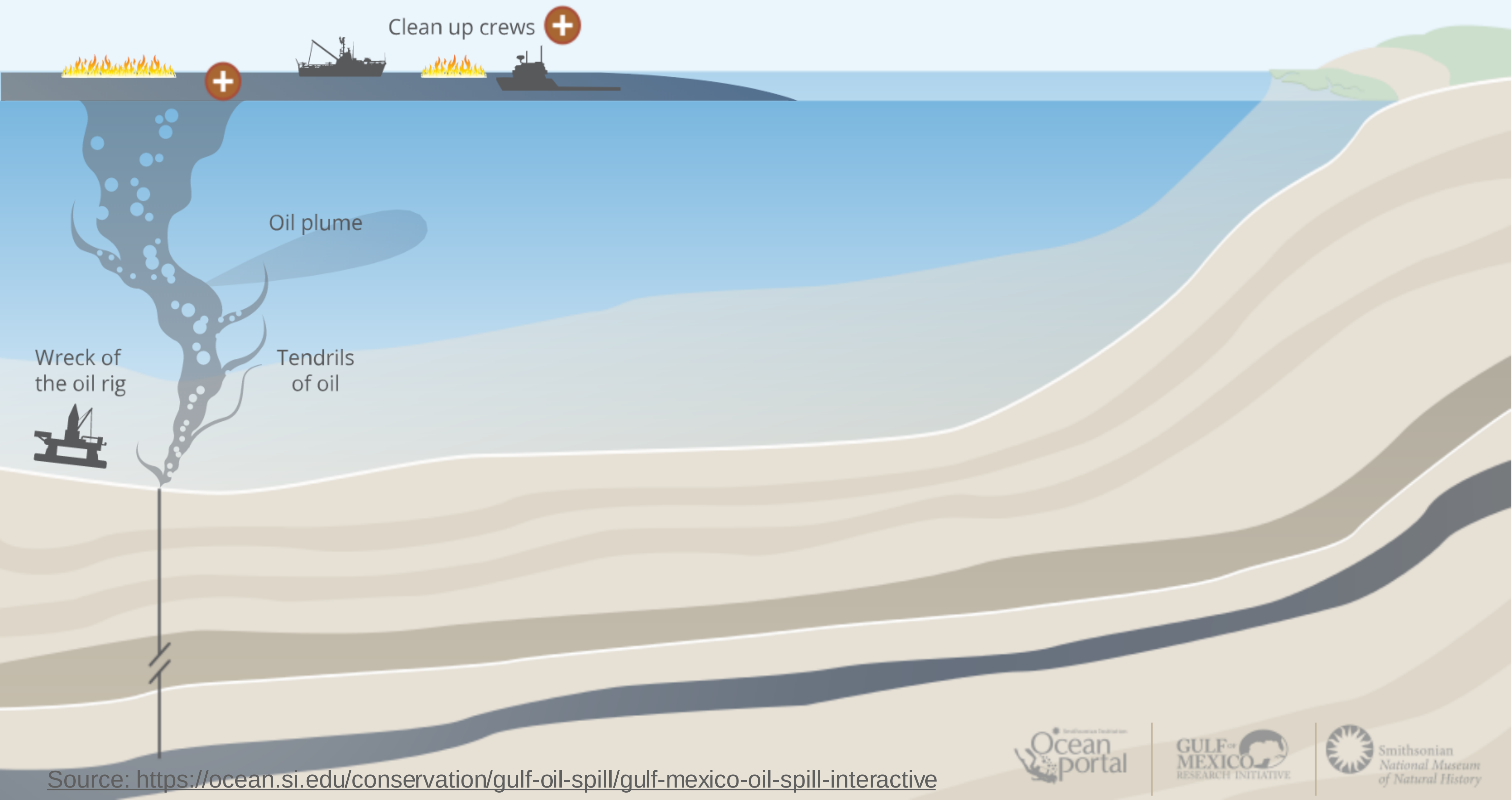
The *Deepwater Horizon* rig sat 42 miles off the Louisiana shore, pumping oil up from deep beneath the seafloor. On the night of April 20, a bubble of methane gas escaped from the well and shot up the pipe towards the surface, causing an explosion and fire. This tragically took the lives of 11 rig workers, while 115 others were successfully evacuated. Crude oil and gases, buried deep beneath the seafloor, began leaking from the oil well 5,000 feet down. Wind, waves and currents spread the oil across the ocean's surface to form a slick, which eventually covered around 5,000 square miles—about the size of Connecticut.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

THE CLEANUP

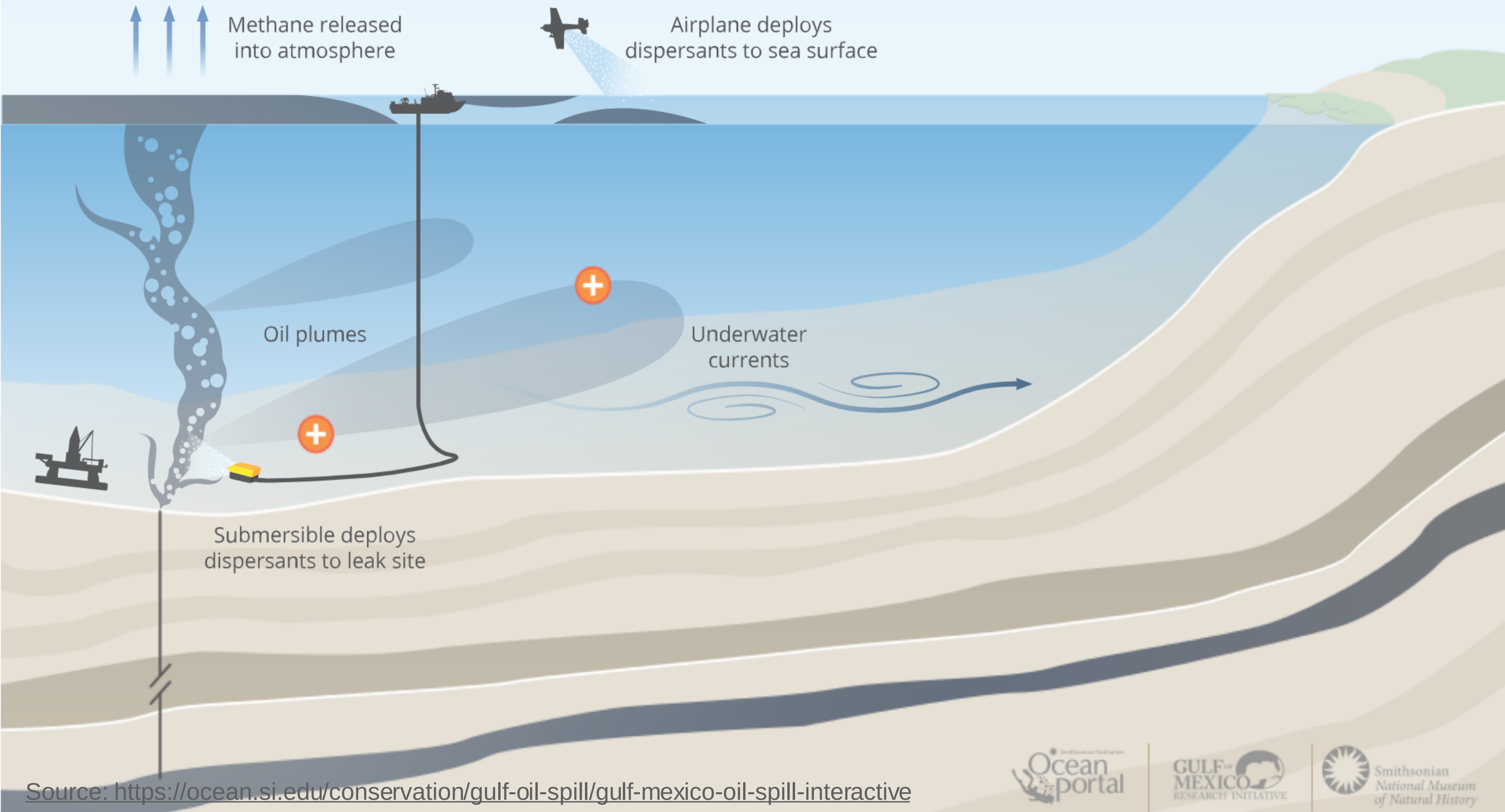
The rig sank on April 22 after burning for more than a day. Workers did their best to stop the oil from washing up on the Gulf shore, where it would be even more difficult to remove from fragile coastal ecosystems. Some wildlife, such as birds and sea turtles, got stuck in the surface slick during cleanup, endangering their lives.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

DISPERSANTS

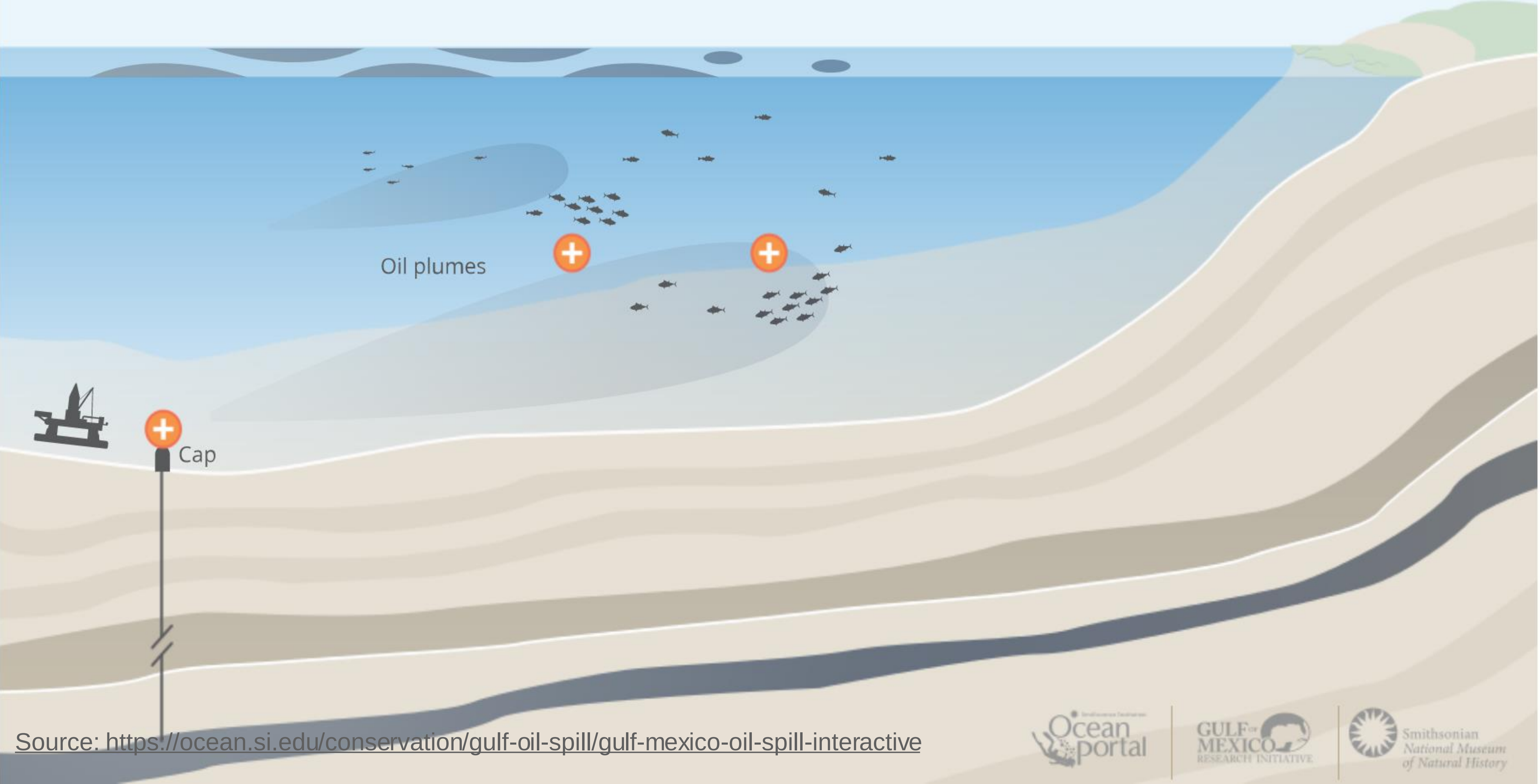
On April 26, BP began adding dispersants to the oil. Dispersants are like strong soaps, which cause the oil to break down and mix with water more easily to speed up its natural biodegradation. As they combined, the oil became less buoyant, forming additional underwater plumes while preventing the droplets from floating to the surface and spreading to the coasts. But dispersants can also enter the food chain and potentially harm wildlife.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

THE OPEN OCEAN

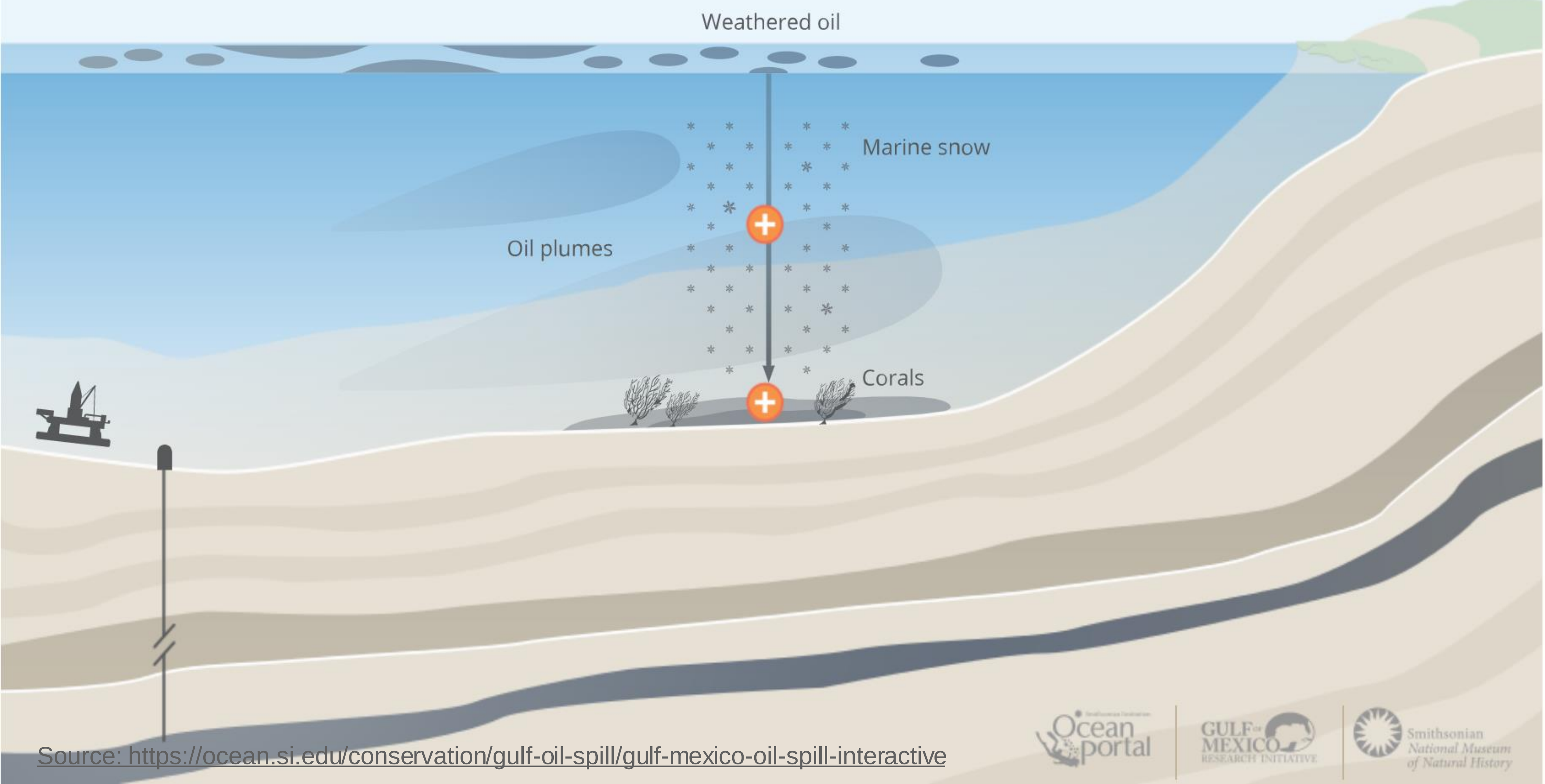
The oil spill occurred more than 40 miles offshore, which was lucky in some ways, as less oil was able to reach fragile coastal ecosystems. But it still interacted with wildlife in the open ocean. It was eaten by organisms big and small, some of which are better able to clear it from their bodies than others. And out in the open, it ran into any developing eggs or larvae carried by the waves—the effects of which we won't know for years to come.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

THE DEEP SEA

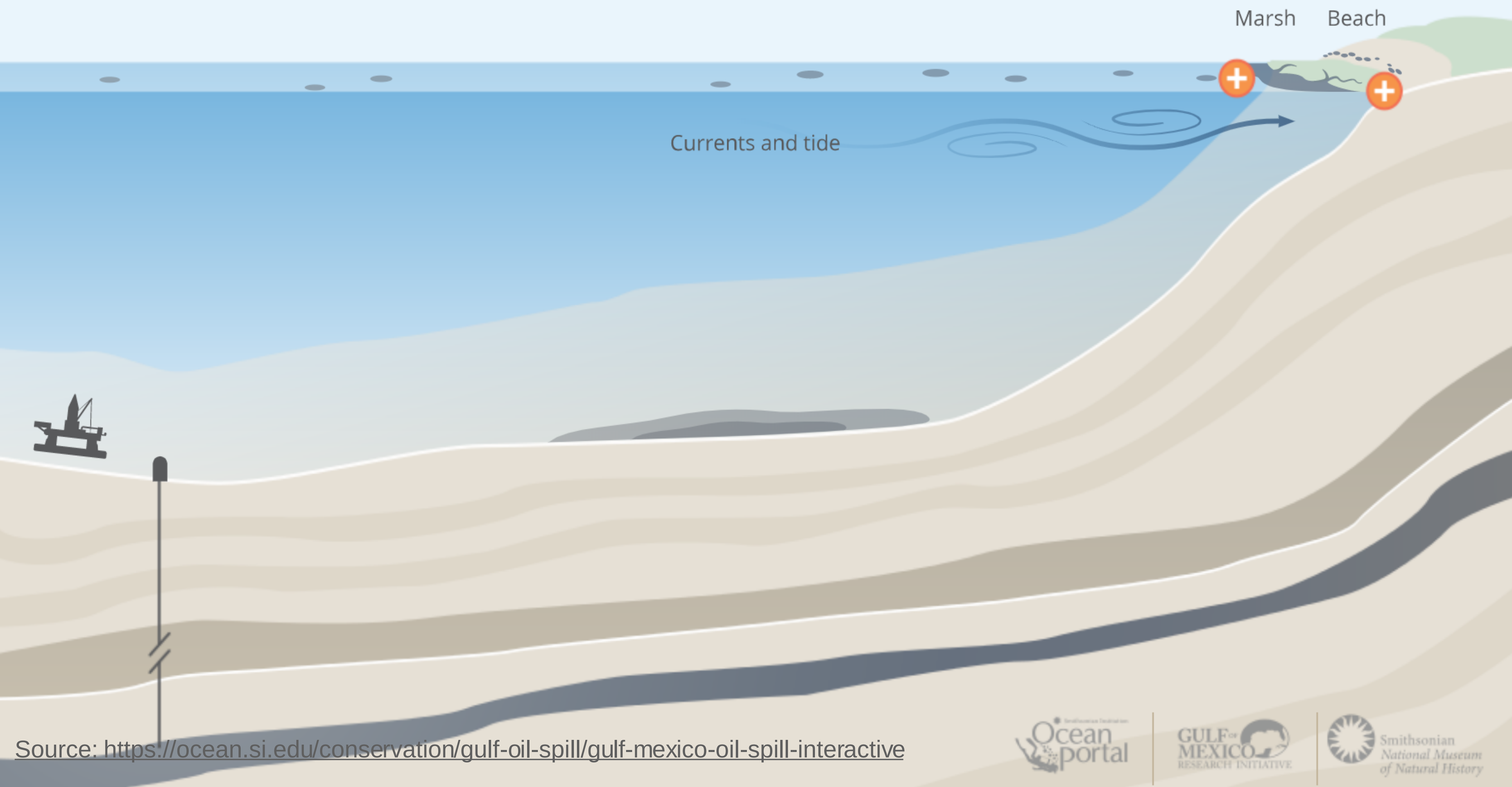
As much as 20 percent of the spilled oil may have ended up on and buried beneath the seafloor, where it interacted with wildlife such as deep-sea corals, fish, mollusks and microscopic foraminifera. When the buried oil is brought back to the surface, it can expose animals to dangerous chemicals again. In addition to the oil and dispersants that fell to the seafloor, sediment was left behind during attempts to plug the leaking well. Understanding how the oil spill affected the seafloor may take many years because it's difficult to access and observe.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

THE COAST

Thirty days after the leak, oil began washing up on the shores of Louisiana. Marshes and estuaries are the worst places that oil can end up. They are difficult to clean without killing the marsh grass itself, and serve as nurseries for young ocean animals. Sometimes the oil becomes buried beneath the mud, where it is slowly released back into the water over decades. In heavily oiled areas of marsh, erosion rates doubled in the years after the spill and little recovery has been observed since. We won't know the full effects of oil in the marshes for years after the spill, when the larvae that would have been exposed to oil are grown up and caught in fisheries.



Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

TODAY

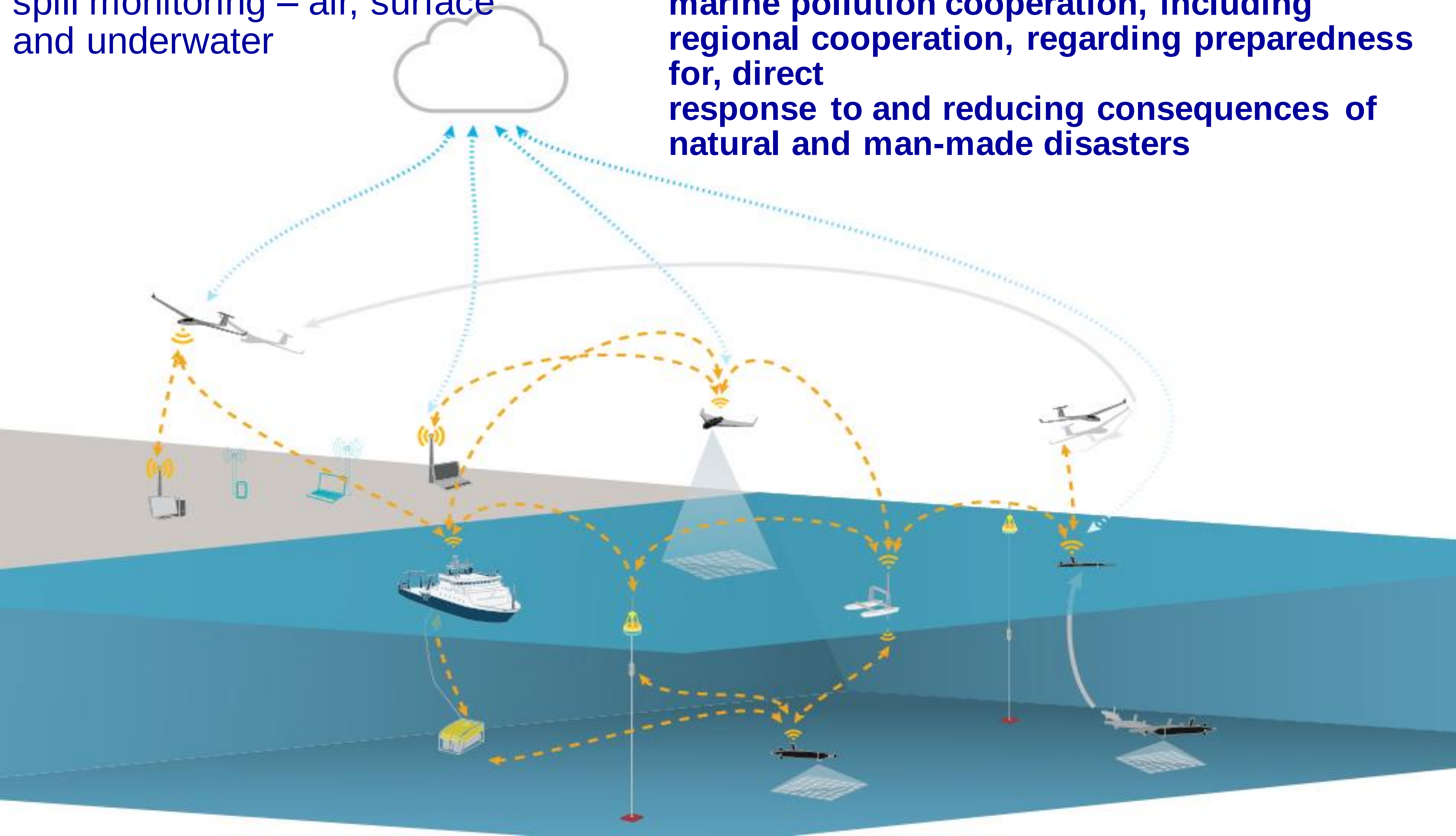
The *Deepwater Horizon* oil spill leaked oil and gas into the Gulf of Mexico for 87 days until the well was capped on July 15, 2010. Today, Gulf seafood is safe to eat and the Gulf is recovering better than expected. Scientists continue to study the effects of the spill and develop technologies to improve upon the cleanup methods and response for any future spills that occur.

Source: https://ocean.si.edu/conservation/gulf-oil-spill/gulf-mexico-oil-spill-interactive

URready4OS - concept

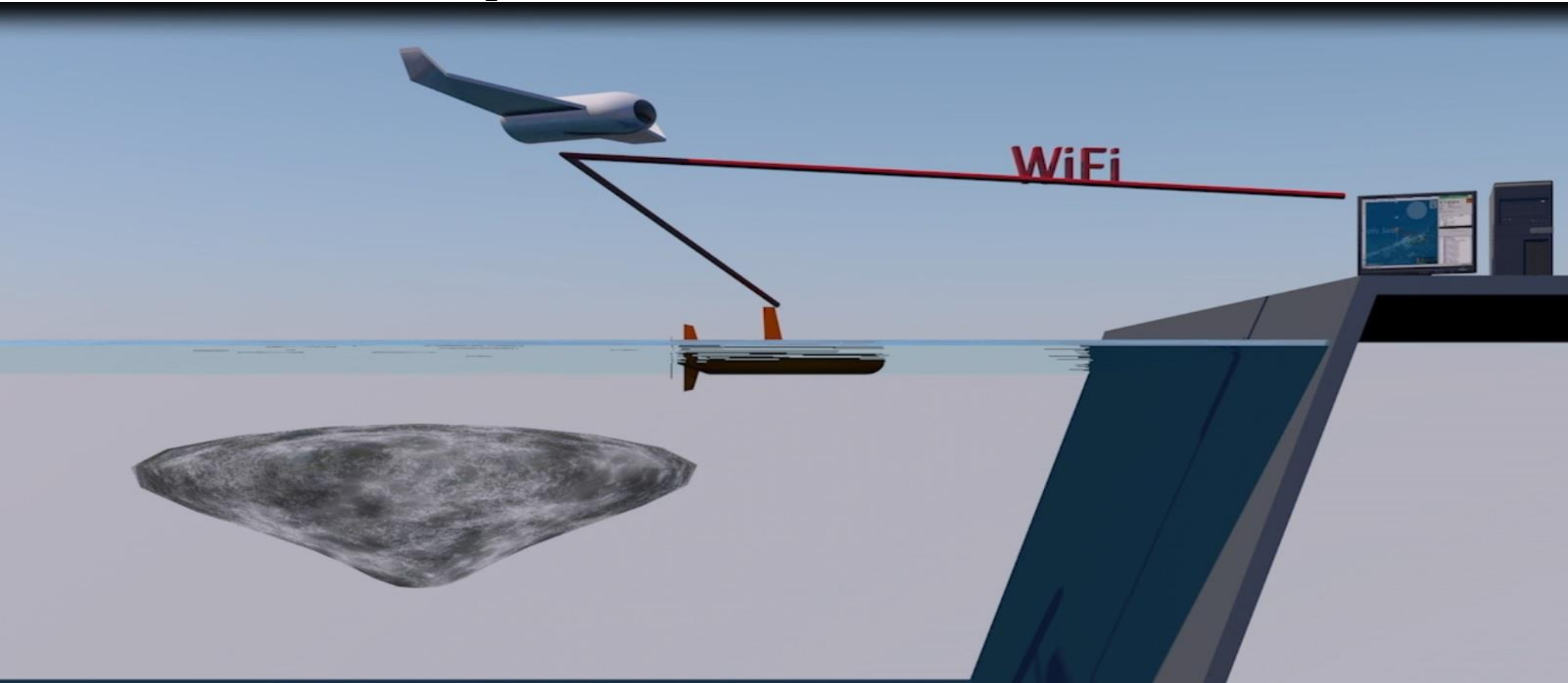
Multivehicle cooperation for oil spill monitoring – air, surface and underwater

aimed at improving civil protection and marine pollution cooperation, including regional cooperation, regarding preparedness for, direct
response to and reducing consequences of natural and man-made disasters



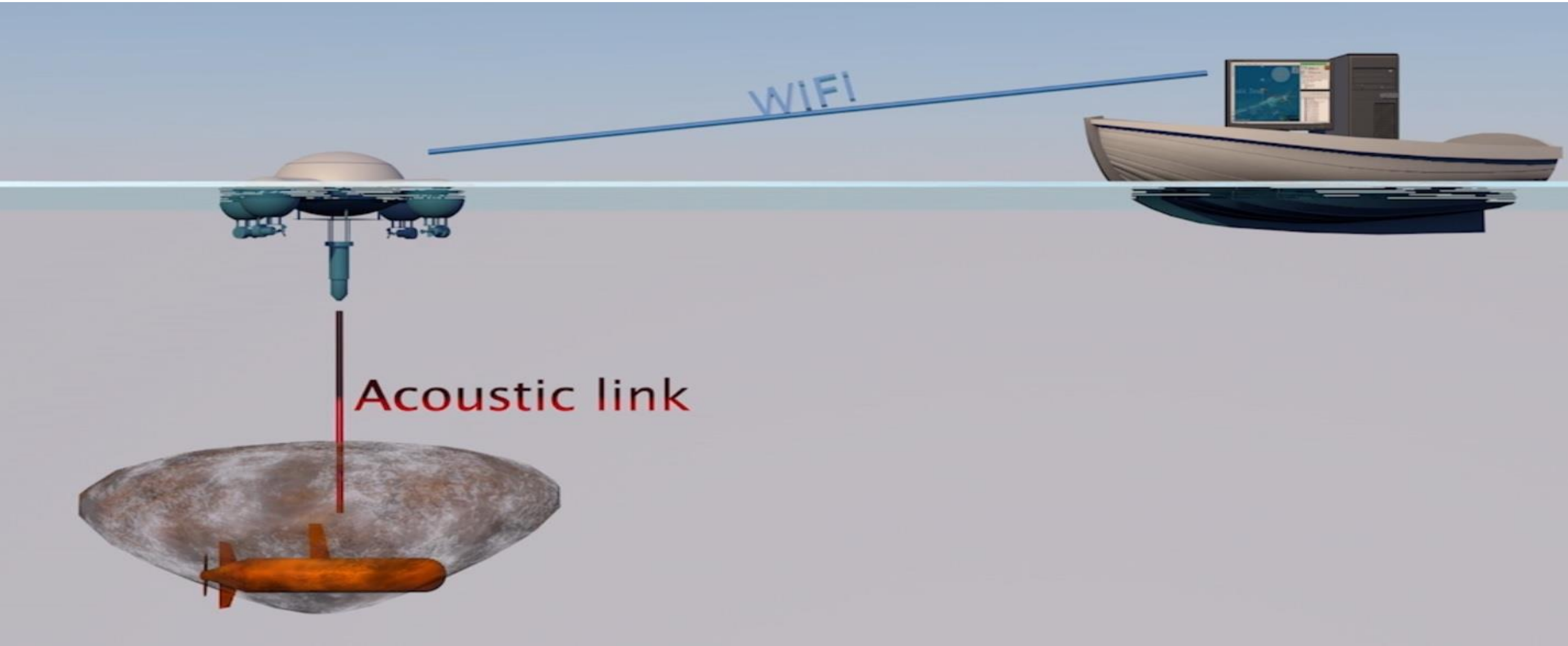
Scenario 1

- AUV scans designated area of the water column.
- when AUV surfaces, log files are transferred (WiFi) via UAV to the ground station.



Scenario 2

- AUV continuously feeds the USV with measurement data via acoustic link.
- USV transfers near-real time oil-in-water concentration data to the mission base via WiFi.

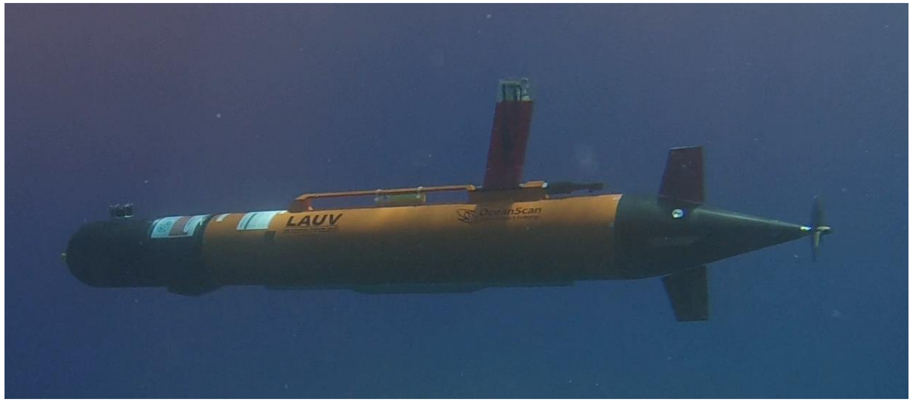


Vehicles used

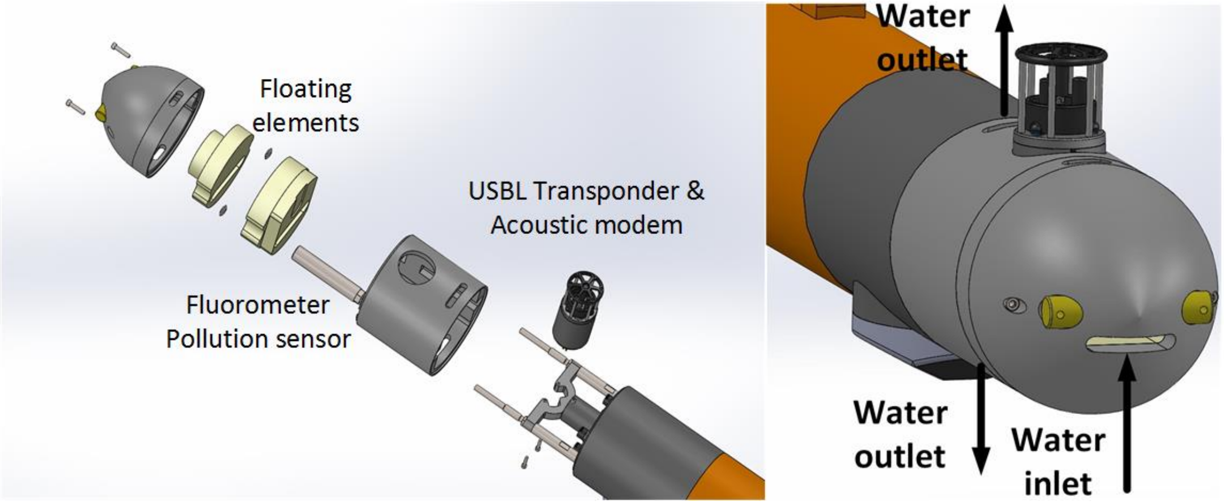
- Fuses measured and telemetry data to provide spatial distribution of the sub-surface plume.
- Benefits of using lightweight AUVs:
  - acquire huge amount of relevant data
  - cost and time-efficient
  - do not require specially certified technical personnel for operation
  - do not require expensive and complicated logistic.

Support of AUV operations

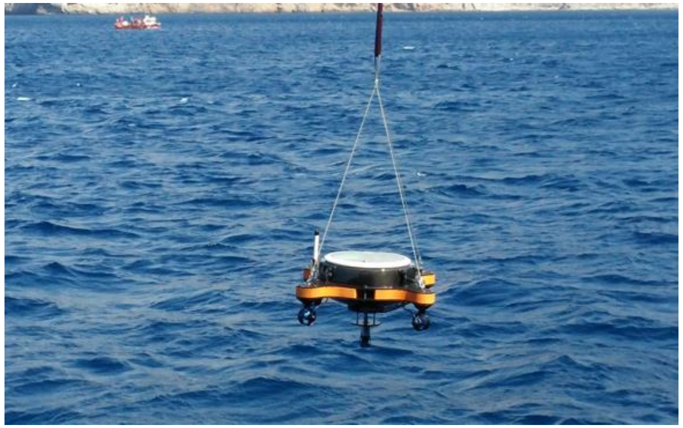
AUV's task is **to scan the underwater area suspected to be polluted.**

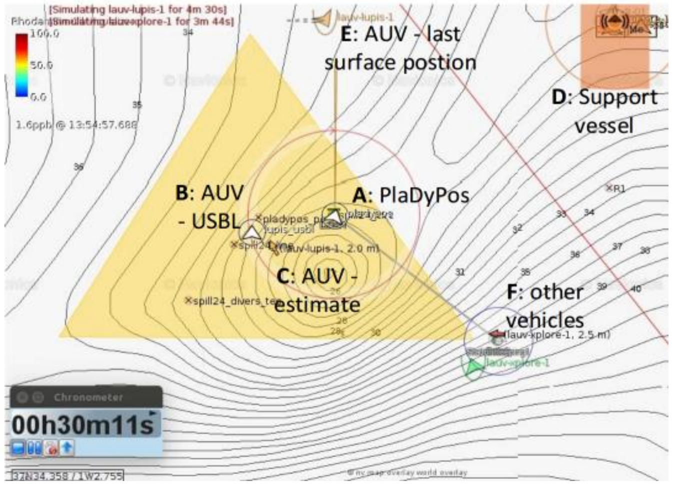


AUV's payload: fluorometer, USBL transponder



Support of AUV operations





Benefits of using the ASV:

- ➢ Ensures reliable acoustic link by tracking the AUV operational area
- ➢ Provides AUV acoustic localization
  - ❖ No need for AUV surfacing
  - ❖ Accurate dana georeferencing
- ➢ IoUT allows an operator to directly access AUV sensors and AUV control system.

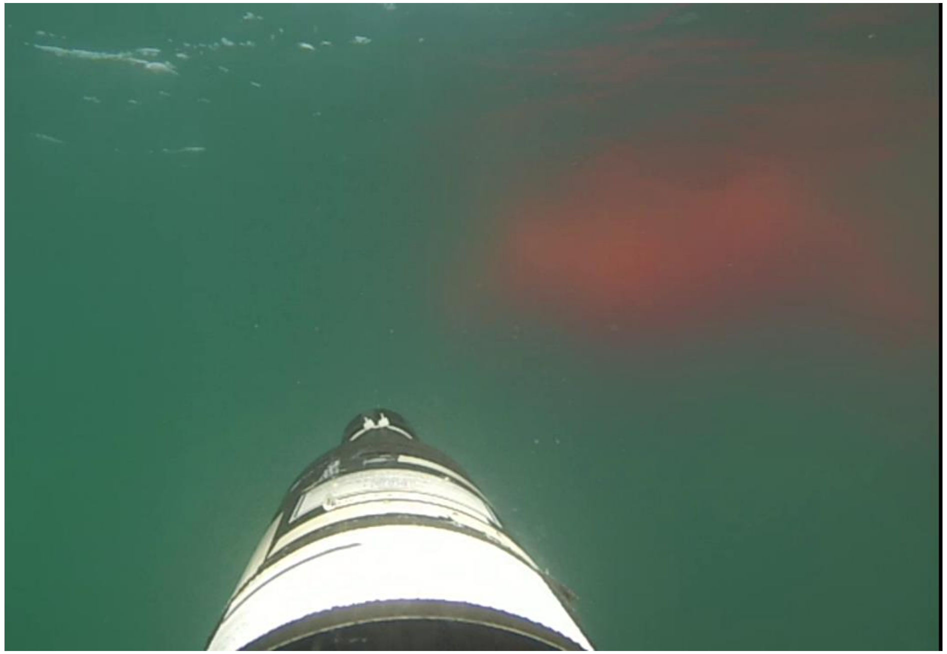
As a result, operator

- ➢ has access to the real-time sub-surface pollution data and
- ➢ is able to change the AUV mission online.

- ➢ Trade-off: quantity of transmitted data vs. frequency of localization


HONDA

Experiments - Underwater



- It was not permissible to create oil pollution in reality
- Oil spill simulated by Rhodamine WT red fluorescent dye, harmless, non-toxic oceanographic tracer

- AUV entering the Rhodamine plume
- Image from the AUV onboard forward looking camera

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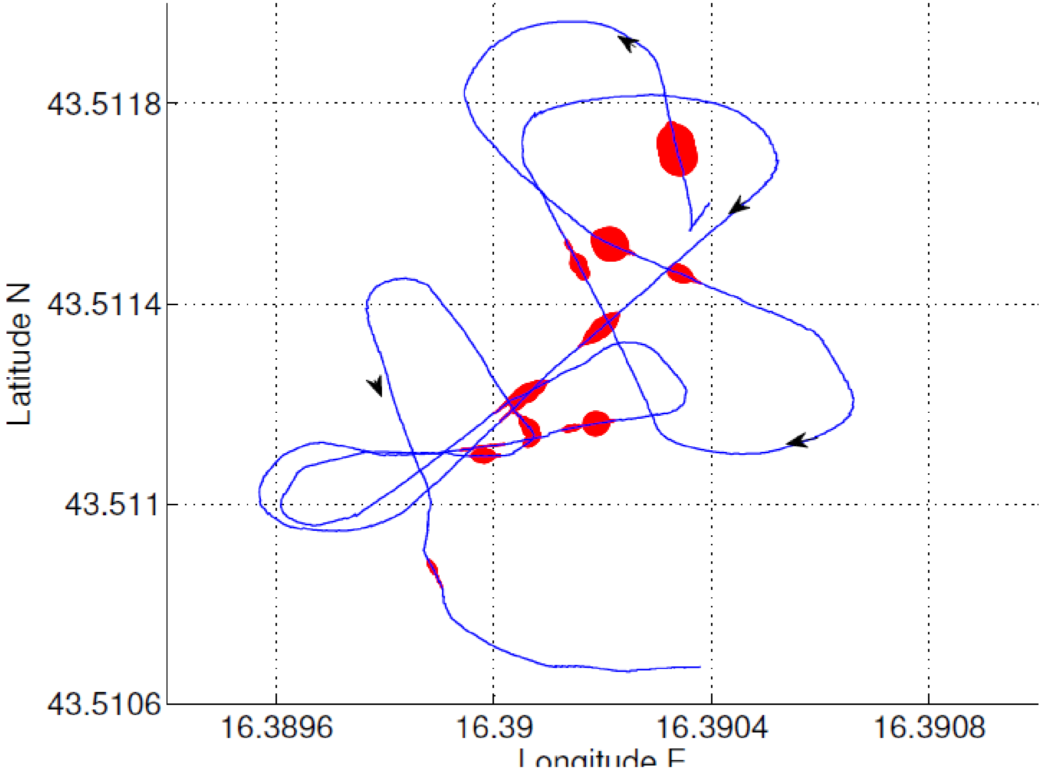
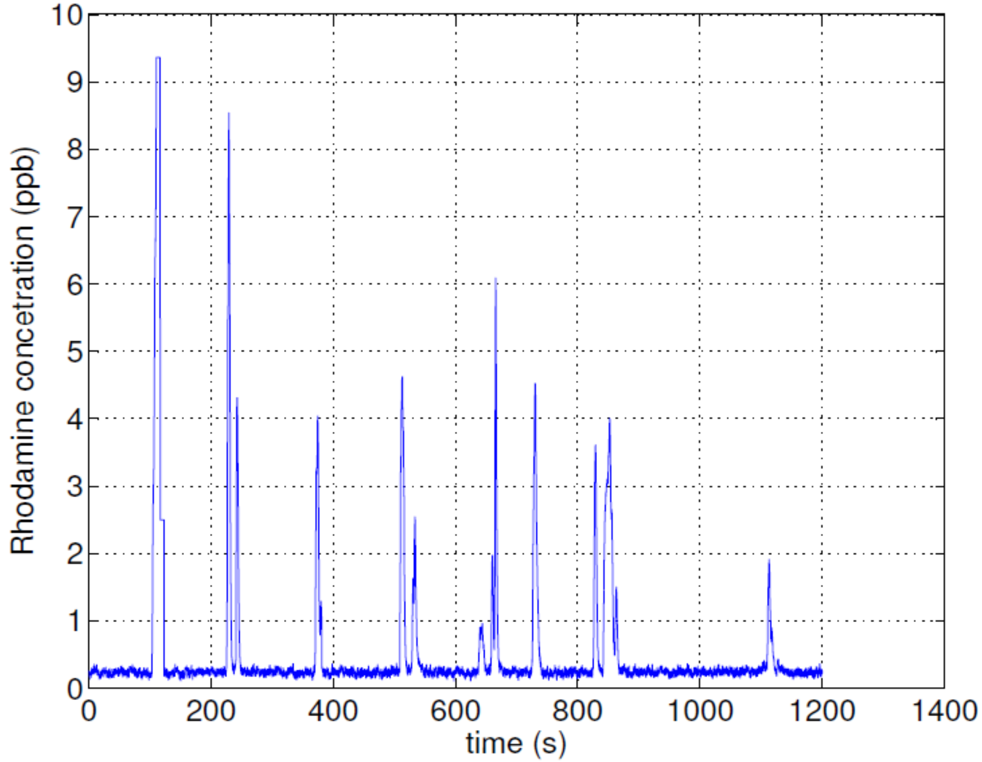
Experiments - results

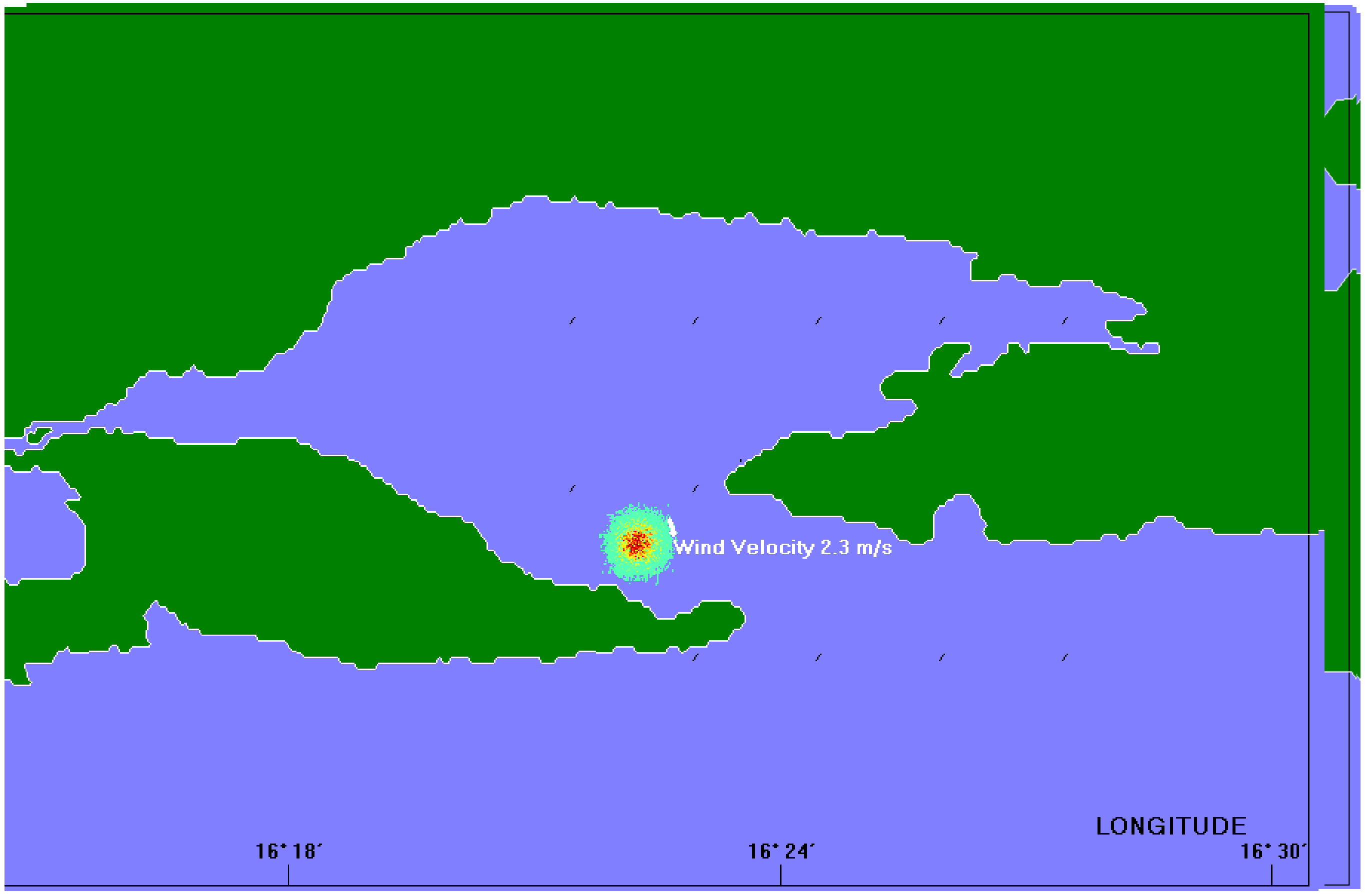




- The system was able to efficiently detect pollution when passing through the plume.
- Data was geo-referenced, logged and visualised
- Figures present results of the single 20 minutes fixed depth mission

Experiments – model

Numerical model takes into account all relevant oceanographic data and geo-referenced, time stamped, near-real-time concentration data.



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Experiments - Air

- UAV is an efficient vehicle for initial survey and detection of the primary spill location
- Communication link (range extender) between the AUVs and the ground station

Image shows:

- The part of the spill area
- Two AUVs transferring log files to the UAV

Short movie link

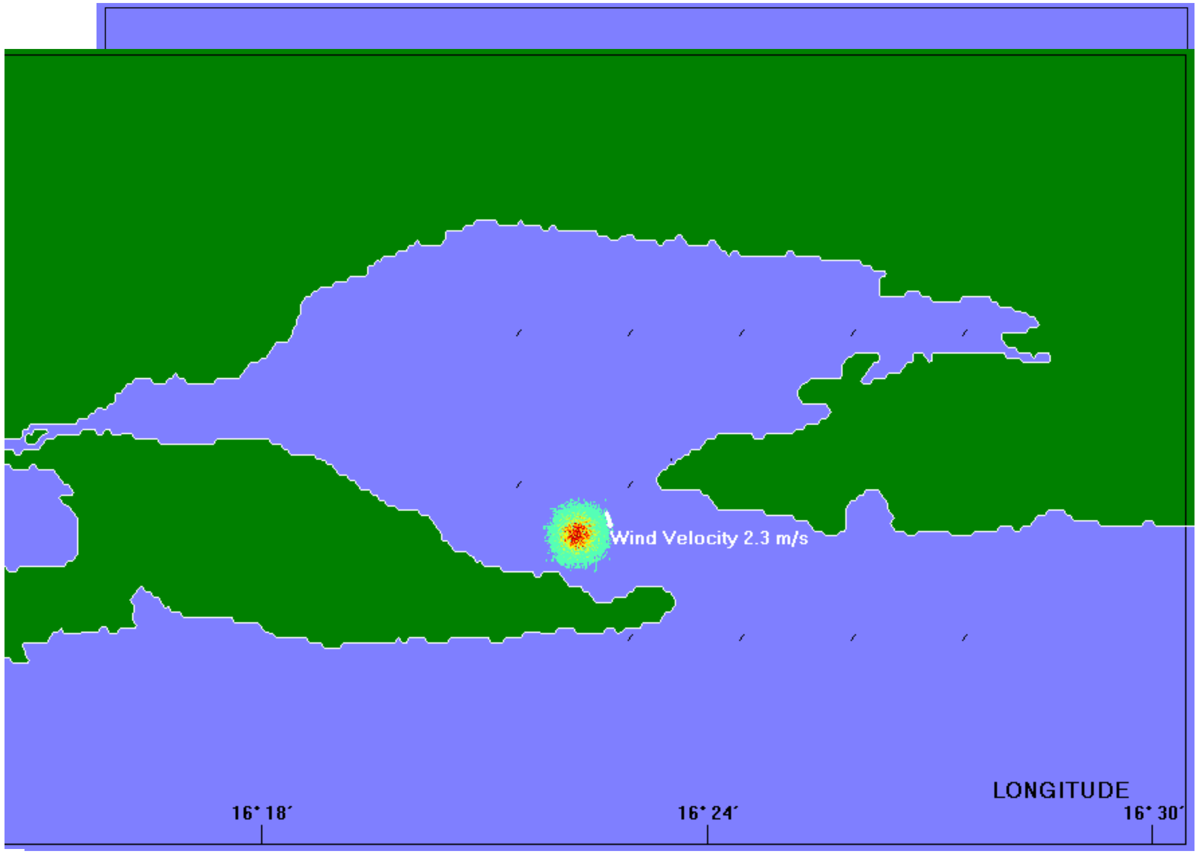
Experiments – Simulation and Modeling

1. Modelling provides initial estimate of spill location, time, depth and very quickly predict the expected trajectory using forecasting data
2. Information from the vehicles feed the oil spill model to predict the fate of the observed plume

The simulations are performed by MEDSLIK II (http://gnoo.bo.ingv.it/MEDSLIKII/)

used by several agencies throughout the Mediterranean

plays a central role in the Mediterranean Decision Support System for Marine Safety (www.medess4ms.eu)



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Marine Biology

Monitoring of sea grass

Posidonia oceanica (Neptune Grass)

- endemic species to the Mediterranean Sea
- provide important ecological services and harbour highly diverse communities
- identified as a priority habitat type for conservation under the EU Habitats Directive (Dir 92/43/CEE)
- seagrasses are among the worlds most threatened ecosystems
- 46% meadows experienced reduction in range and 20% severely regressed since the 1970s

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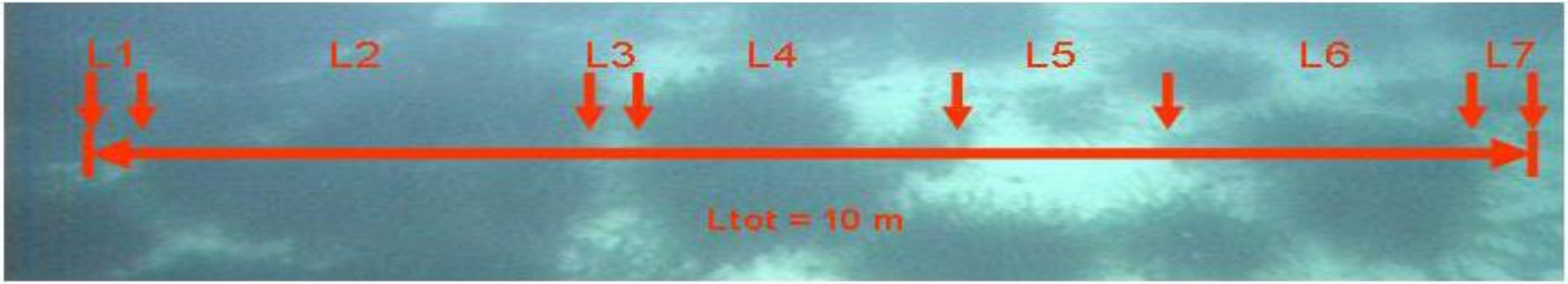
Bottom coverage – LIT existing method

- Scuba diving - bottom cover is assessed by Line Intercept Transect (LIT) technique
  - 10m long measuring tape
  - positioned on the randomly selected seabed transects
  - measure the lenght covered and not covered by *P. Oceanica*
  - compare determined region



L1 = 0.4 m = dead *matte*
L2 = 3.0 m = *P. oceanica*
L3 = 0.3 m = dead *matte*
L4 = 2.2 m = *P. oceanica*
L5 = 1.5 m = sand
L6 = 2.1 m = *P. oceanica*
L7 = 0.5 m = sand

P. oceanica = L2 + L4 + L6	= 7.4 m	**74%**
dead *matte* = L1 + L3	= 0.6 m	**6%**
sand = L5 + L7	= 2.0 m	**20%**

Study area

Bay Lucica

Resources

- 2011 - IVER2 (University of Zagreb)
  - SportScan-Imagenex sidescan & HERO2 underwater camera
- 2012 - IVER2 (OceanServer)
  - high definition L-3 Klein's UUV-3500 sidescan
- 2012- LAUV (OceanScan)
  - YellowFin-Imagenex sidescan & digital camera with illumination module
- 2013 - REMUS100 (Hydroid)
  - high definition EdgeTech 2205 sidescan sonar

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Depth Limits

- Meadow limits/boundaries were established using remote sensing data:

1. **aerial photography** in the shallow areas, i.e. up to 10 m of depth

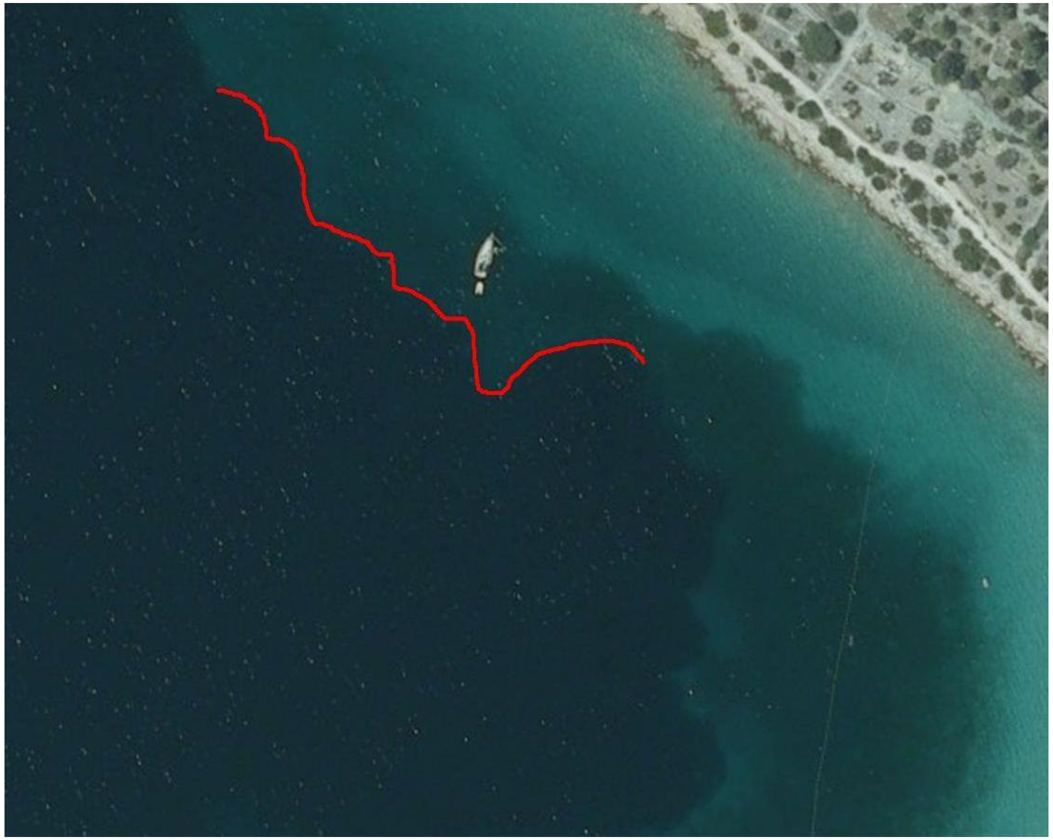
\+ provides big coverage and ensures efficient evaluation of the upper depth limits

\- does not provide data for seagrass identification

\- does not provide data for evaluation of the limit type

\- cannot be used for lower depth limit evaluation

\- requires ground truthing to verify that obtained results correspond to the real situation



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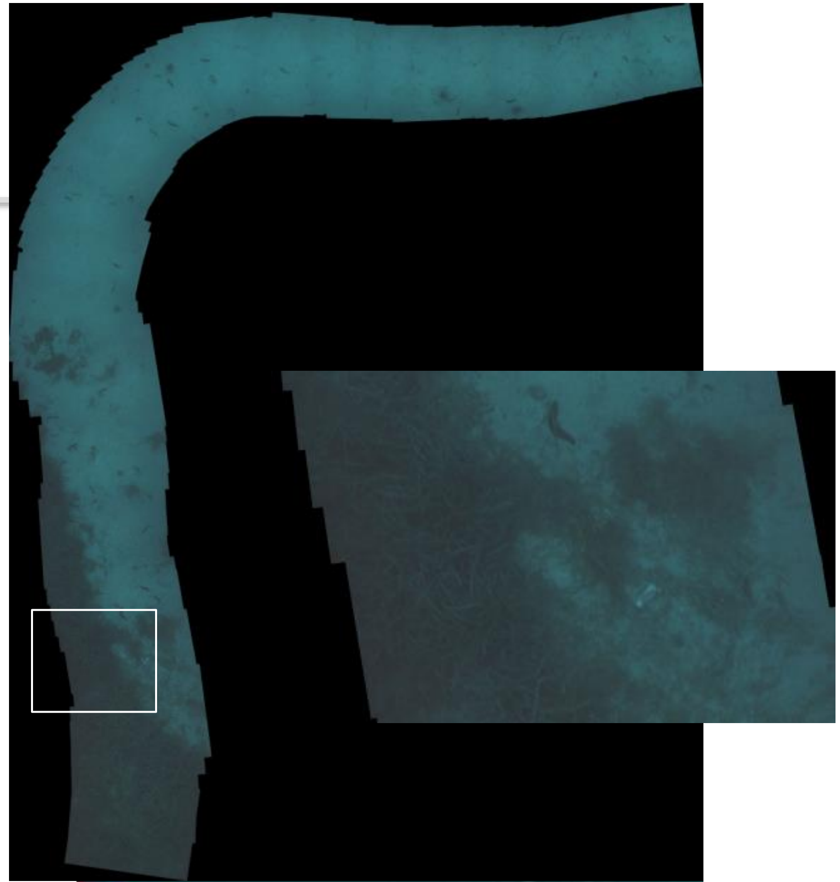
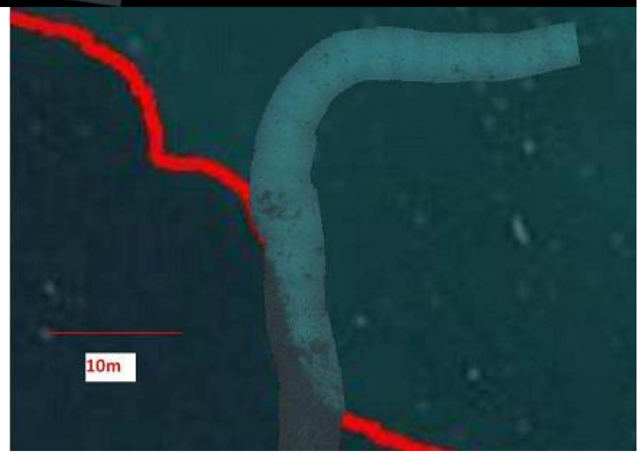
Depth Limits

2. **underwater in-situ photography (collected using AUV)** is perfect supplement to the aerial photography

+ identification of the seagrass
+ accurate evaluation of the limit type
+ evaluation of the lower depth limits
+ present real situation on the seabed
- relatively small coverage, one image covers few meters of the saebad.





Depth Limits

3. sidescan sonar data

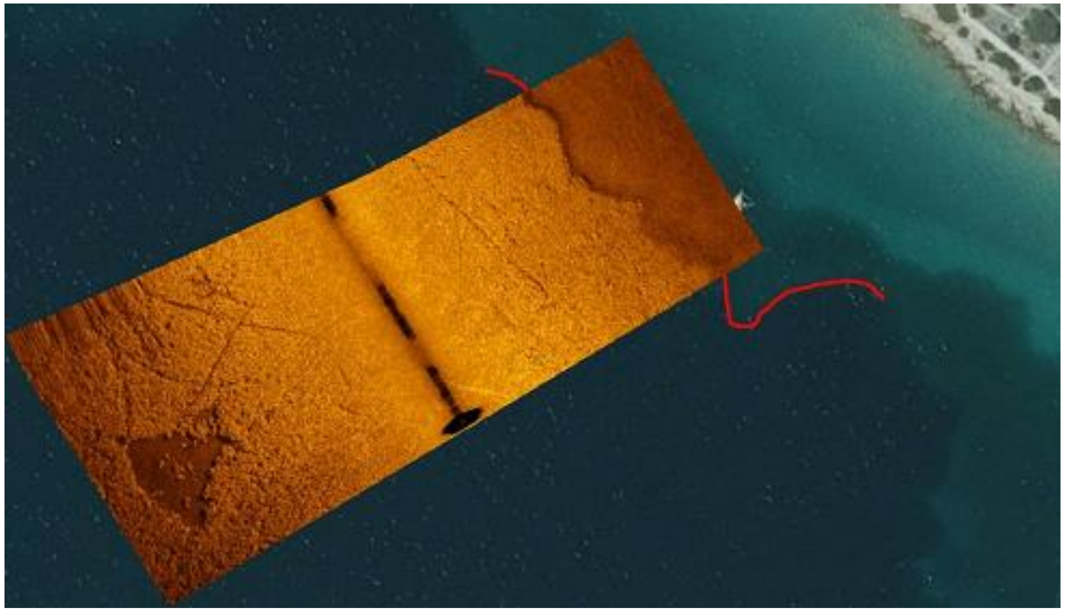
\+ works for both limits

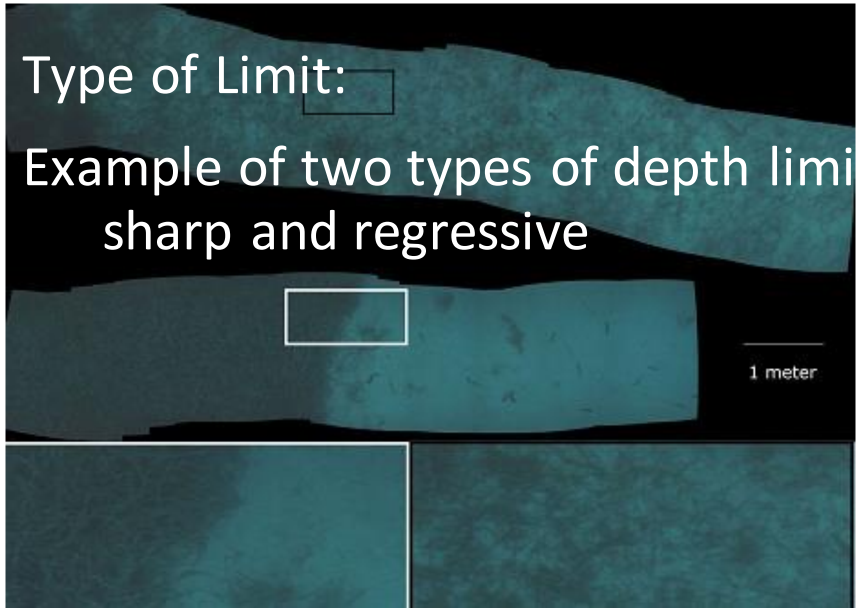
\+ big coverage

\+ handy to fill the gaps not covered by more accurate methods/sensors

\- does not provide data for seagrass identification

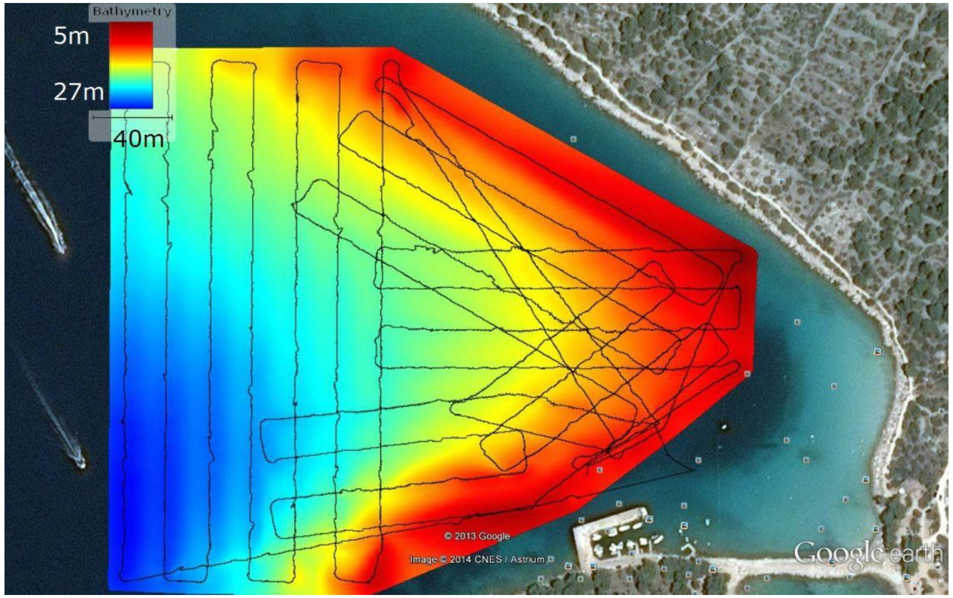
\- geo-referenced data suffers from higher localisation inaccuracy





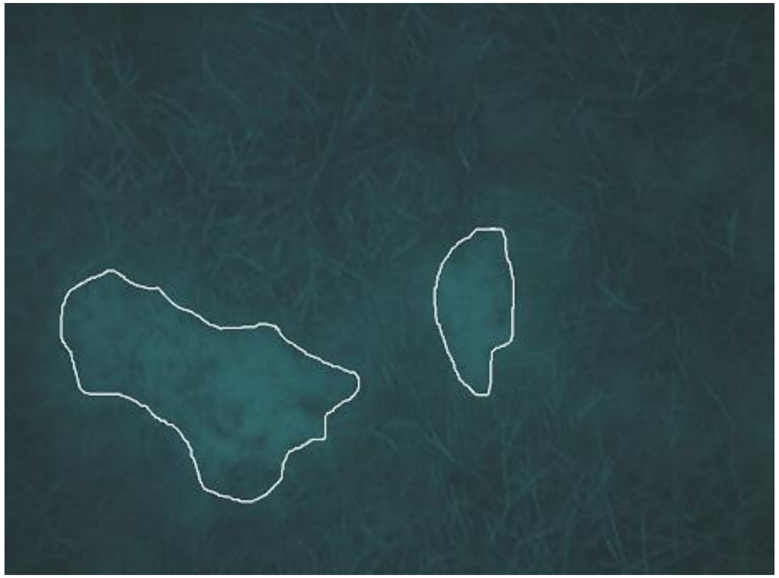
Depth Limits – Final results

- Upper and lower depth limits presented in GIS
- Upper depth limits are on the depth of 5 to 10 met.
- Type of limit: mostly sharp with few exception where type is regression.
- Lower limits at the depth of 21 to 25 meters,
- Type of limit: mostly of regression type.



Bottom coverage – Underwater images collected by AUV

- AUV collects number of seabad images on desired and fixed altitude
- Automatic estimation:
- simple offline algorithm – pre-processing and brightness segmentation of dark regions of *P. Oceanica (*University of Zagreb)
- does not perform seagrass identification, related published papers [8], [9]
- seagrass is identified by the human operator



81%

43º 49’ 30” N
15º 34’ 10” E

[8] M. Barisic, D. Nad, and A. Vasilijevic, “Texture segmentation applied to p. oceanica beds’ upper boundary tracking by rovs,” in Proceedings of the 3rd IFAC Workshop on Navigation, Guidance and Control of Underwater Vehicles, vol. 3, 2012.
[9] M. Massot-Campos, G. Oliver-Codina, L. Ruano-Amengual, and M. Miro-Julia, “Texture analysis of seabed images: Quantifying the presence of posidonia oceanica at palma bay,” in OCEANS - Bergen, 2013 MTS/IEEE, June 2013, pp. 1–6.

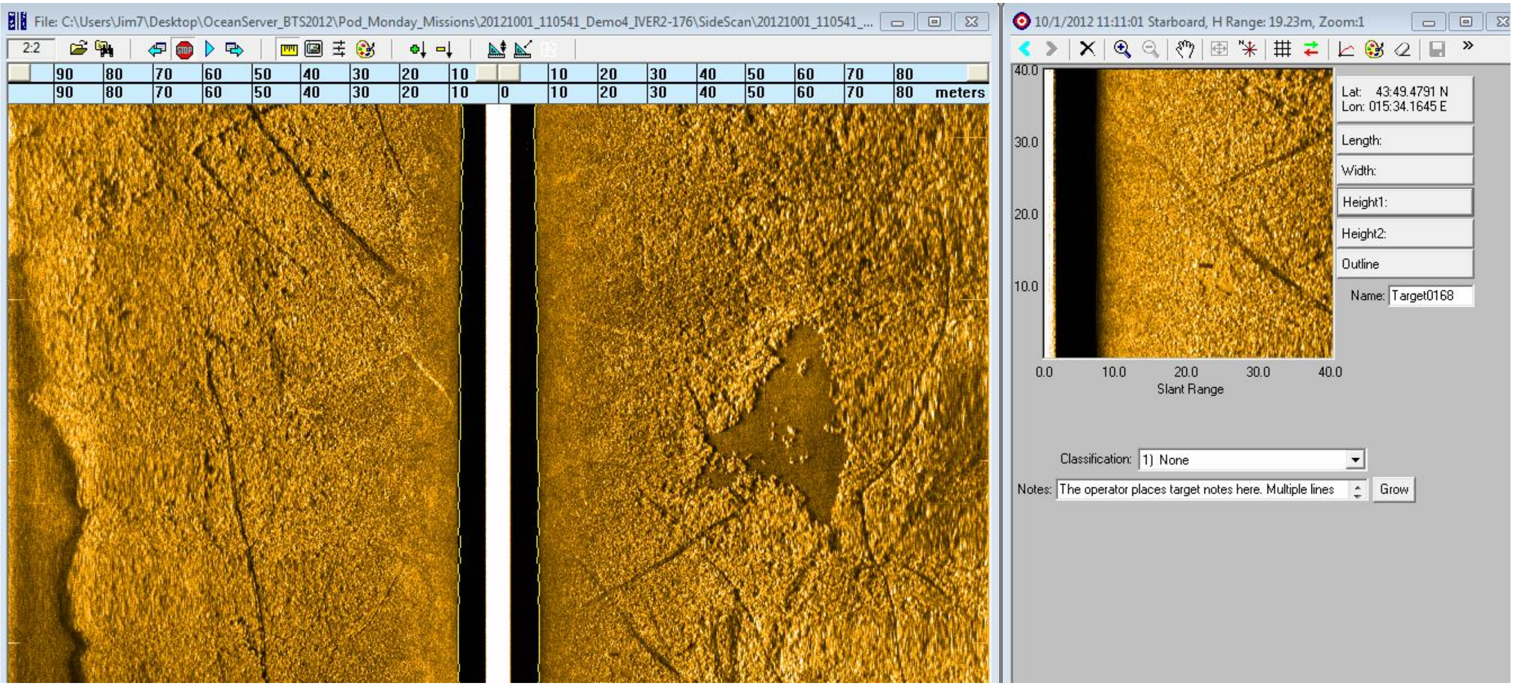
Final Bottom coverage – Underwater images collected by AUV

- Percentage cover of the image is linked to the geographical position of the image
- All together represent geo-referenced bottom coverage data set
- AUV collects huge number of meadow images
- It gives us possibility to generate very dense meadow coverage grid

Different tones of green represent percentage of the bottom coverage (0% -100%)

Added value

- Collected data interesting for long term monitoring:
- seabed sediment texture and bathymetry of the monitoring area
- water quality data (physical, chemical and biological) e.g. salinity
- sidescan imagery reveal evidence of mechanical damages done by anchoring
- comparison of the consequents monitoring periods provides information related to progression or regression of damage



1st spotted in France in 1995

Marine biology missions

[June 2006](#) – search for carnivorious sponge inside the sea cave !!

Marine Archaeology

History of the ship (Gnalić shipwreck)

Gagliana grossa, built in 1569 in Venice for
Benedetto da Lezze, Piero Basadonna and Lazzaro Mocenigo

Gagliana grossa, cast off Venice in late October 1583. and
sunk near Gnalić island begining of November 1583

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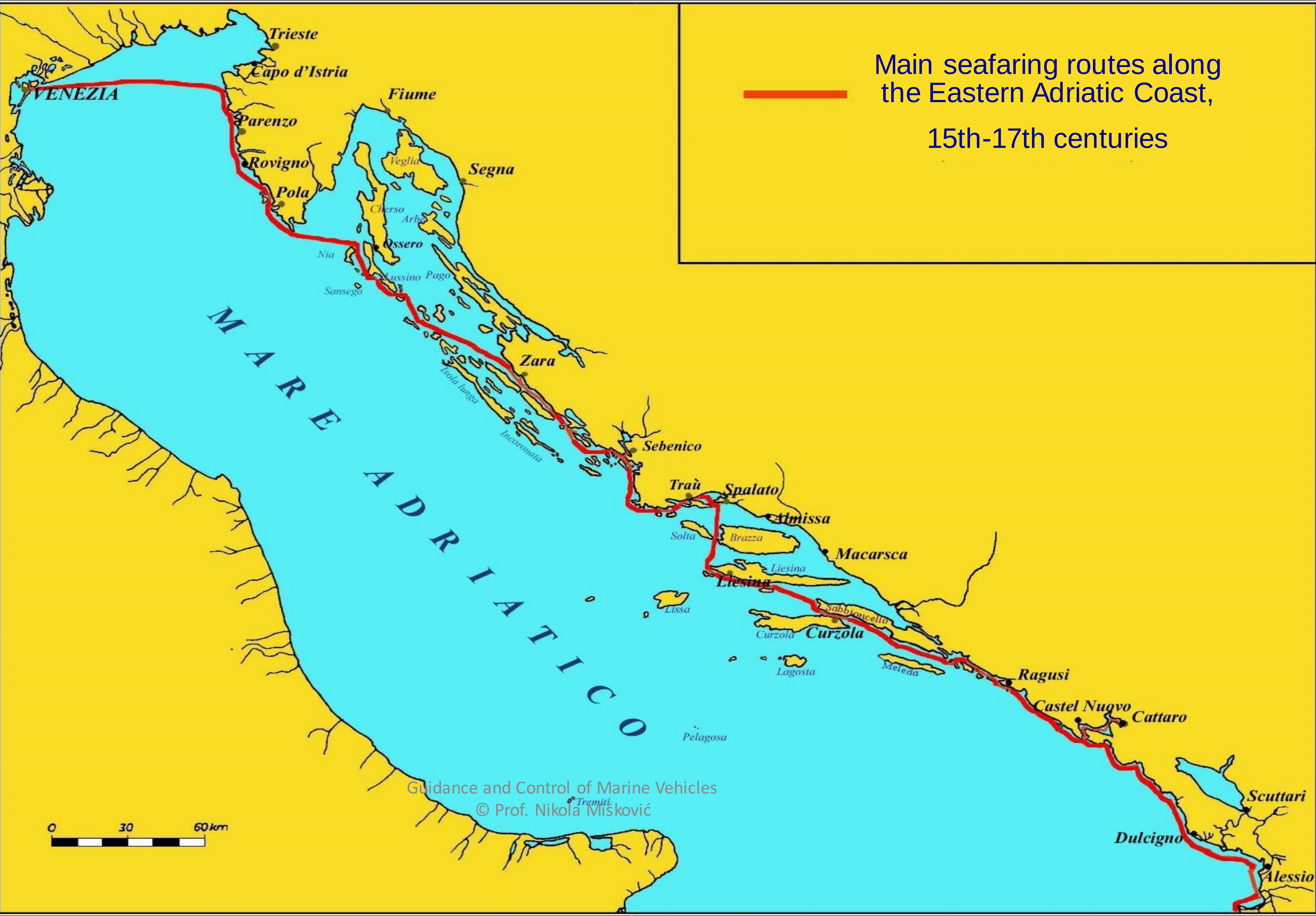
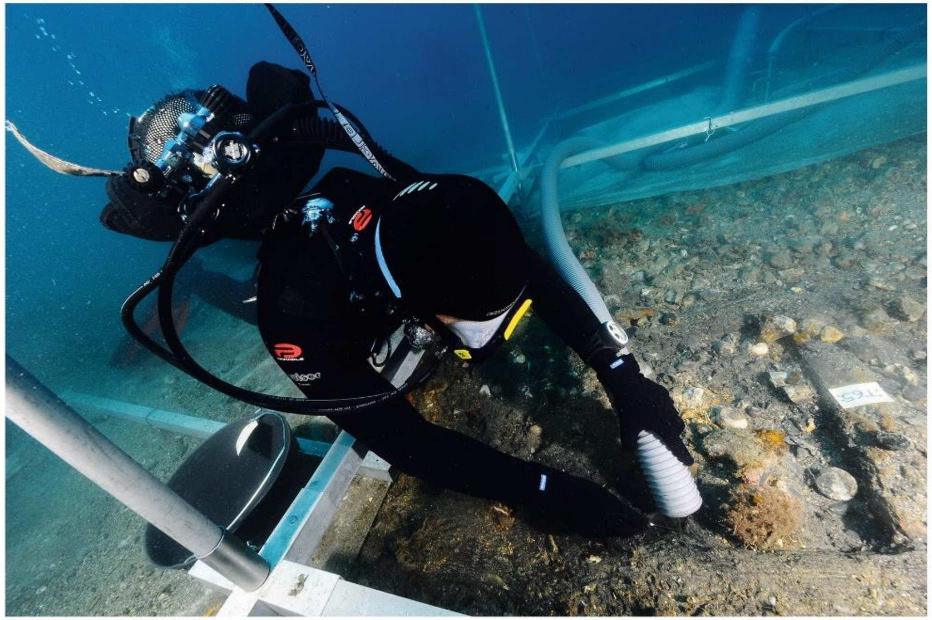


Main seafaring routes along the Eastern Adriatic Coast, 15th-17th centuries



Gnalić 1967

Gnalić 2012

Slide courtesy of Irena Radić-Rossi

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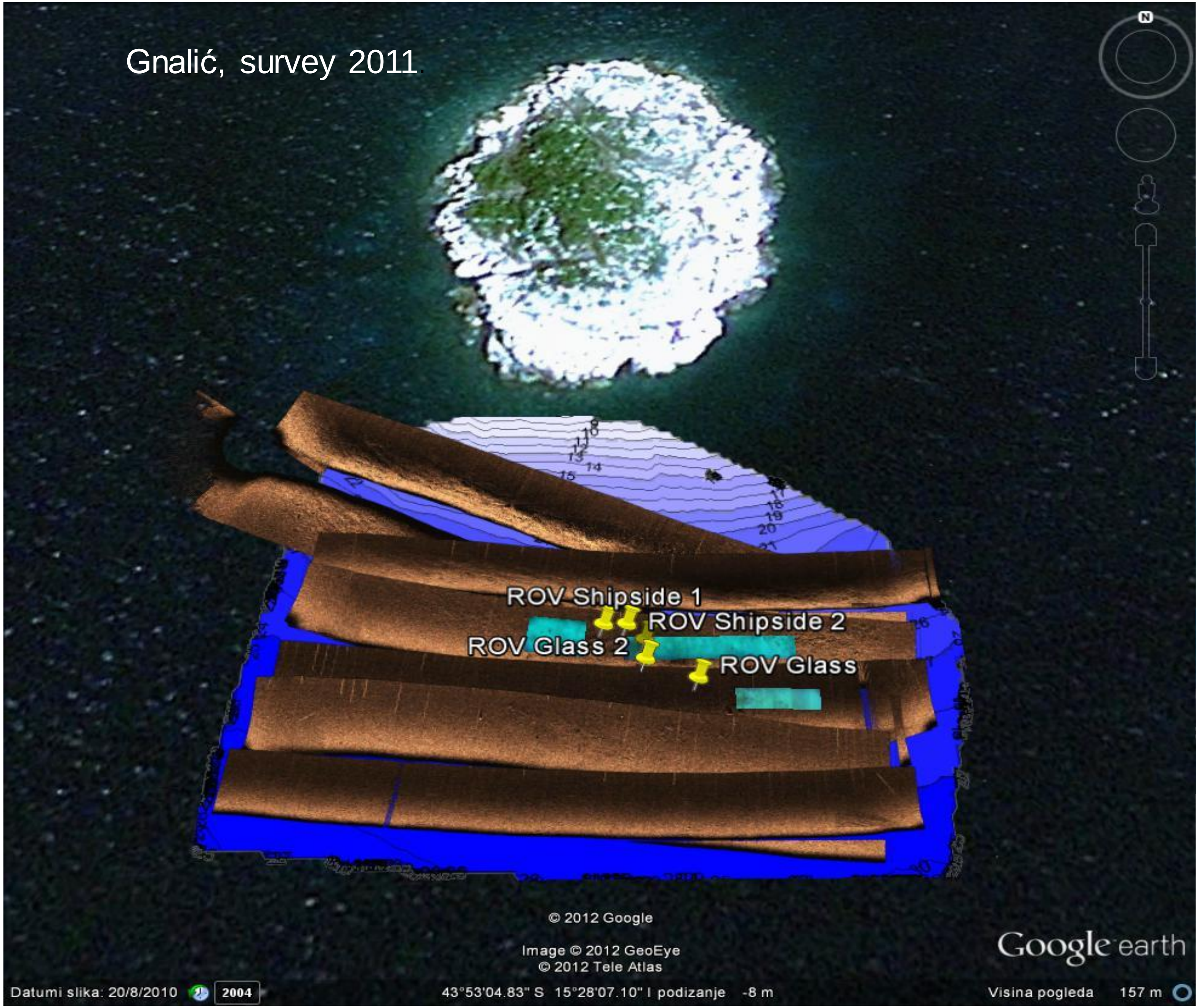

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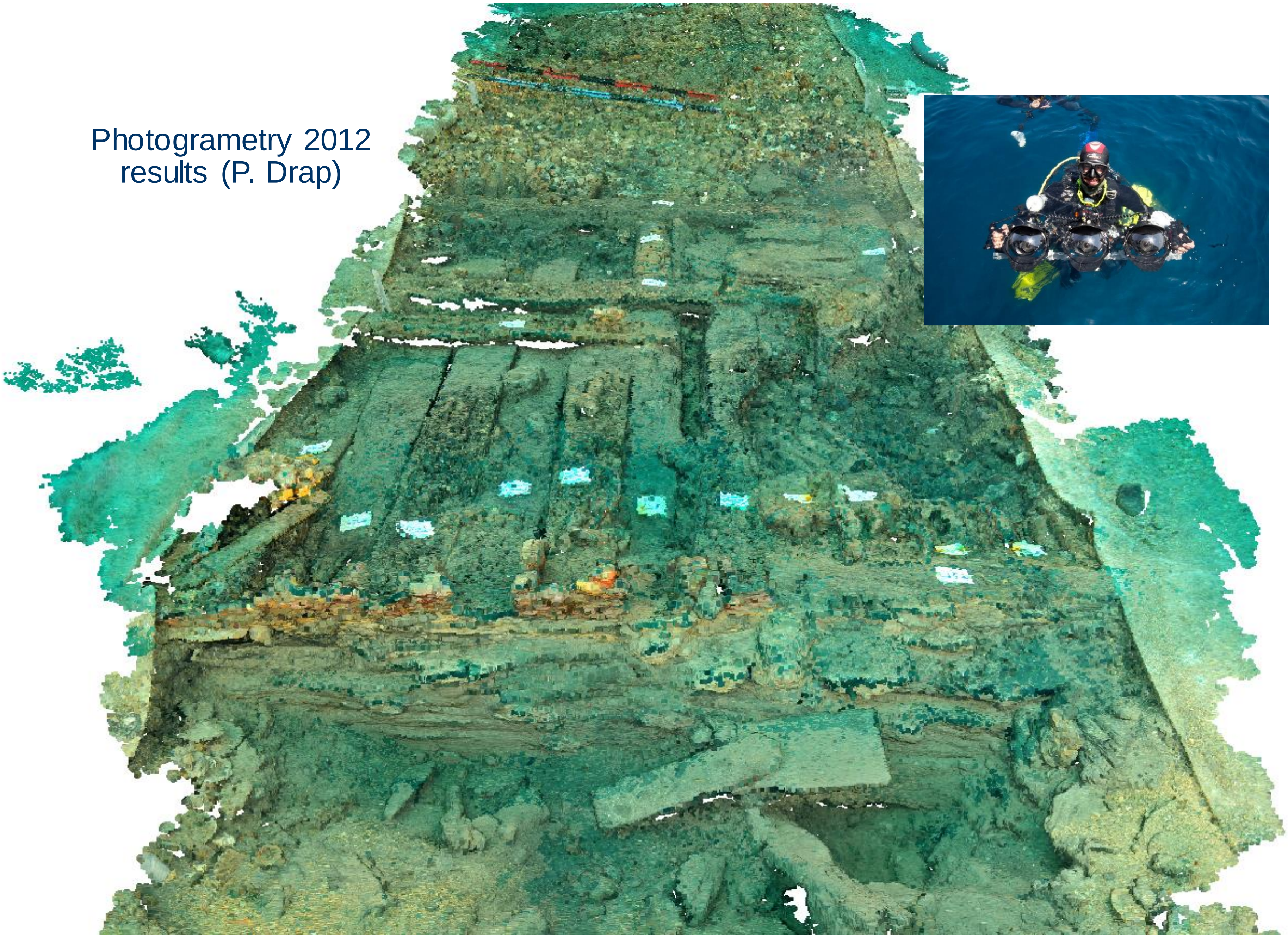
Photogrametry 2012
results (P. Drap)

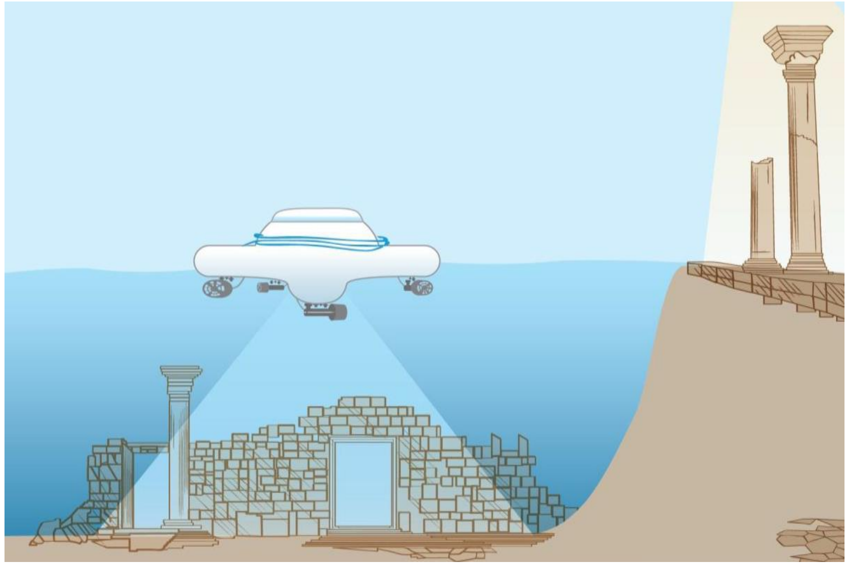


Motivation and Challenges

- Driving force behind technological advances - The need to document sites comprehensively, accurately, and quickly.

Challenges:

- the need for technology to be affordable and robust,
- with efficient data acquisition and post-processing
- archaeologists must be able to interpret the results and publish them according to archaeological conventions



Surface ASV mapping system

- Problem: **Navigation and localization** are among the most difficult problems underwater
  - ASV system: using the GPS (DGPS) and DVL for navigation, the problem is avoided in shallow coastal underwater archaeology
- Problem: the **slow acoustic communication channel**, only post-mission data availability
  - ASV: offers a fast wireless real-time communication link with the base
- Challenge: direct **competition with human divers**
  - ASV: ability to take thousands of instant georeferenced measurements and photos becomes clear advantage when the survey area gets larger or deeper, or the time available for field operations becomes shorter.
  - ASV is designed to complement human capabilities. To take over a dangerous, deep or time consuming work from the diver

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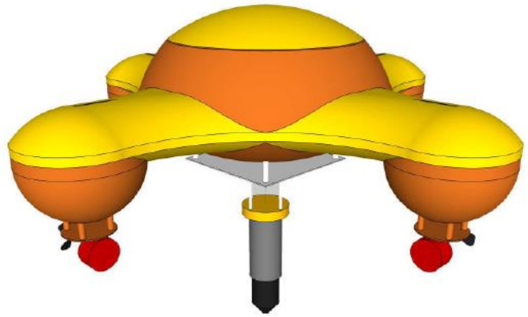
ASV - PlaDyPos

•**Pla**tform for **Dy**namic **Pos**itiong:

- Motion in the horizontal plane in any direction;
- Over-actuated with 4 thrusters forming an X configuration;
- 0.35 m high, 0.7 m wide, weighs 25kg, without payload;
- Quick mission programing
- ROS based architecture
- Easy deployment



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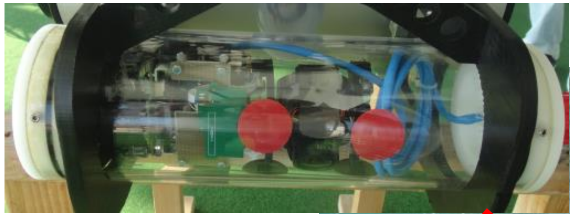
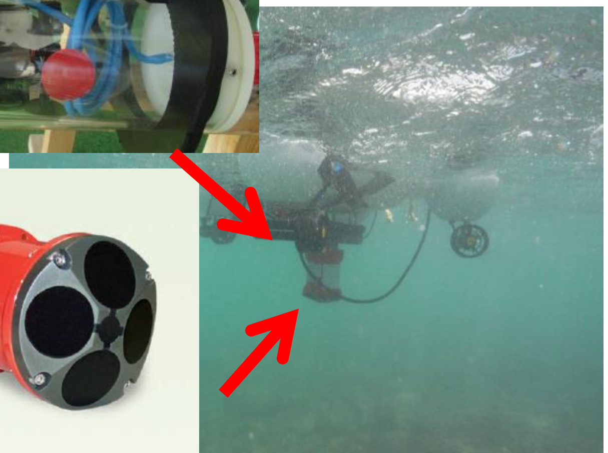
PlaDyPos - Payload

•**Pla**tform for **Dy**namic **Pos**itiong - Payload:

- WiFi link

- Doppler velocity logger (DVL) LinkQuest 600 Micro
- measures speed over ground and altitude with the rate of 5Hz and 0.2% of full range
- Takes 20 points per second or at cruising speed of 1 knot, point cloud density of 40 points per square meter
- Low light Mono camera Bosch FLEXIDOME IP starlight 7000 VR in a waterproof housing.
- Provides Geo reference imagery when fused with telemetric data
- 1/3 CMOS HD 1.4MP sensor, 60 FPS @ 720p, light sensitivity: 0.017 lx in color, 0.0057 lx in monochrome.





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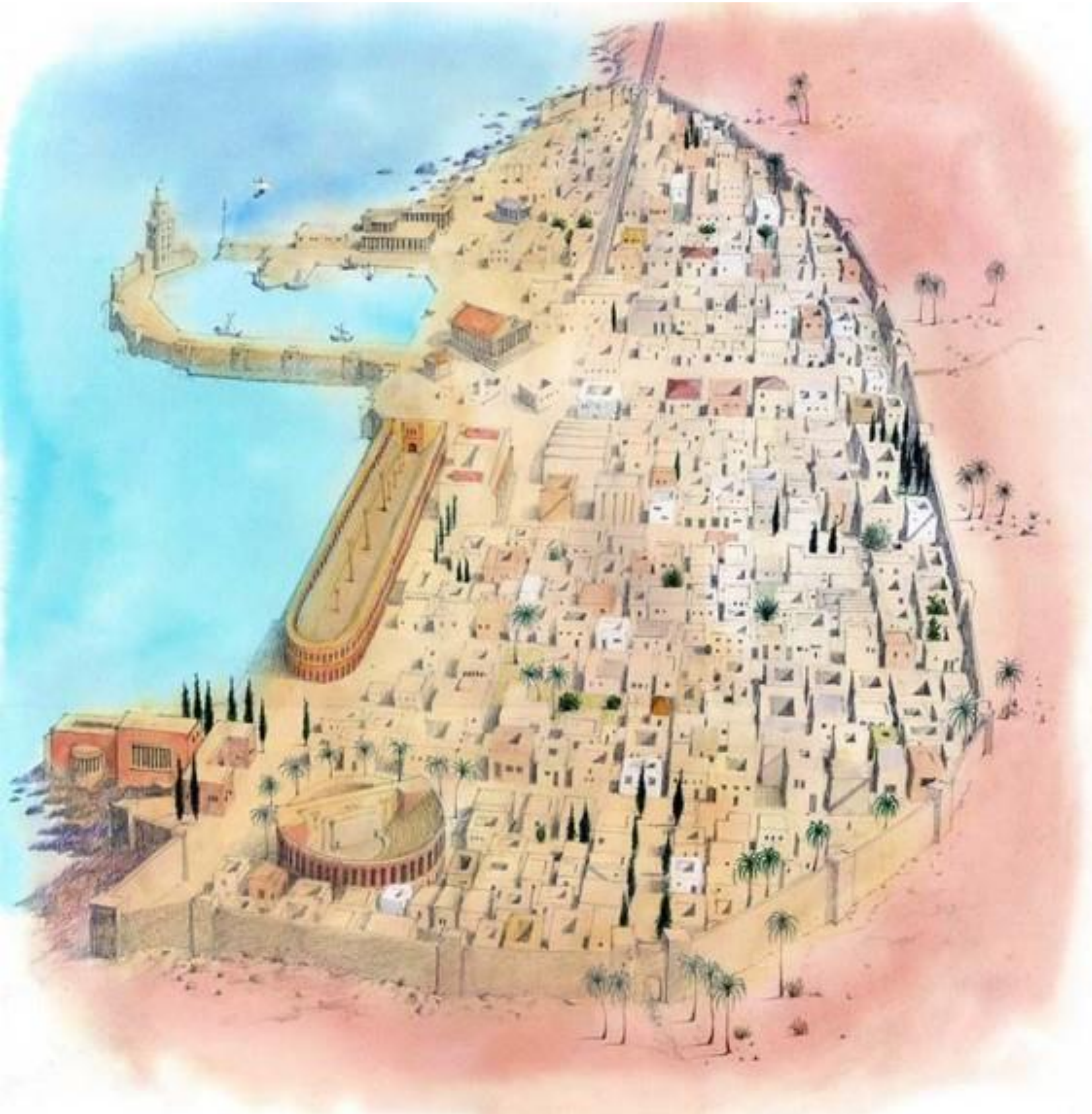
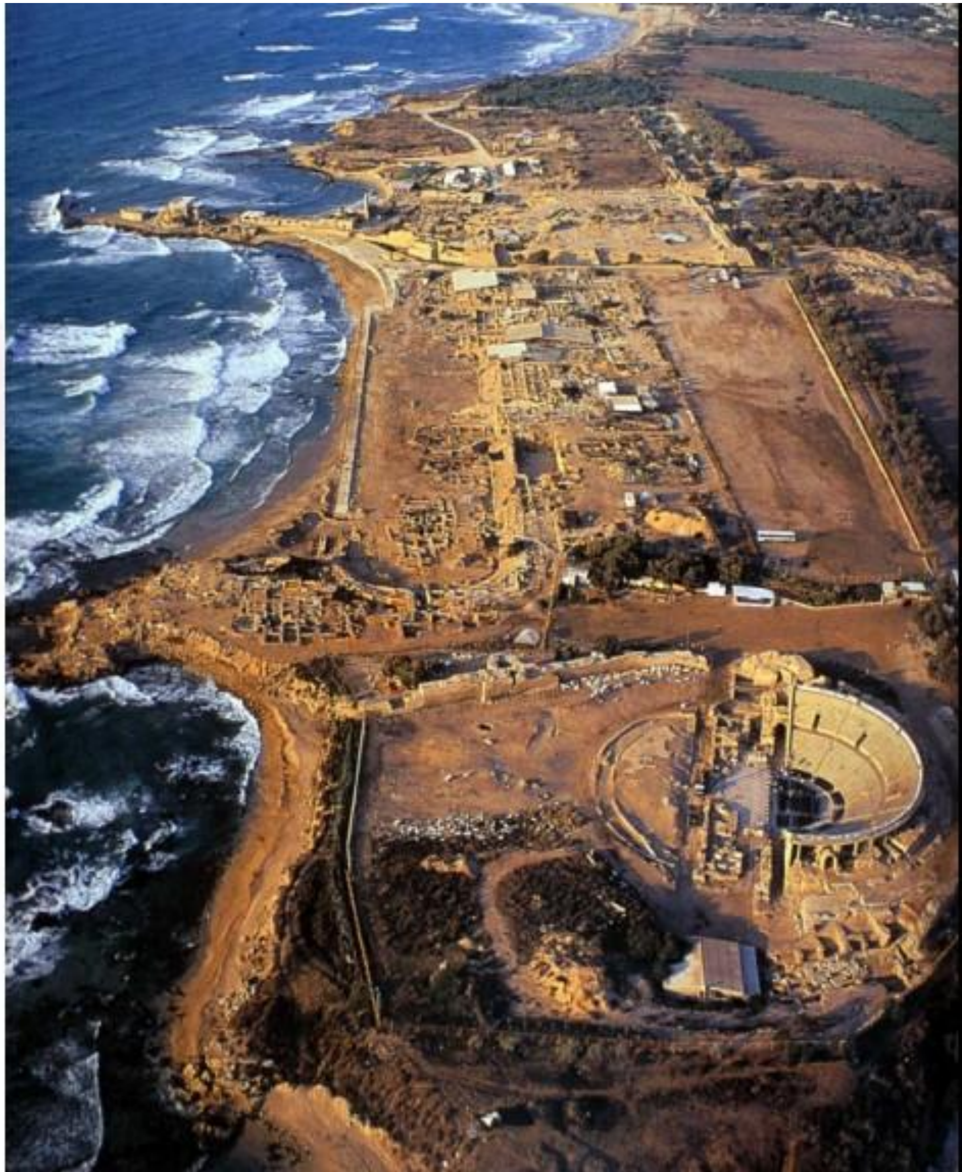
Caesarea Maritima





Caesarea Maritima

- Built by king, Herod I of Judaea for his patron, the Roman emperor Caesar Augustus
- Completed in the last decade of the first century BCE
- The name Caesarea came from the family name of Caesars
- Artificial harbor encompass an area over 200,000 m2
- City itself grew to be five times the size of Jerusalem
- The sunken foundations of the breakwaters and quays are buried in sand and scattered afar, presenting a challenging puzzle for archaeologists trying to reconstruct Herod's original plan.

Caesarea Maritima

- Movement of sea and sand, erosion and the gradual merging of natural and man-made features over the past two millennia makes:
- mapping one of the Mediterranean's largest ancient ports complicated and ambitious task.
- recording strategies must take this into account.
- Detailed manual recording took place in specific areas but the overall site plan remains at best an incomplete patchwork
- We can now integrate a vast amount of georeferenced bathymetric and photographic data into a GIS, we are no longer forced to choose between coverage and accuracy
- Still, there has been no large-scale integration of the available data with information from excavations over the last 60 years.

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Caesarea’s inner harbor

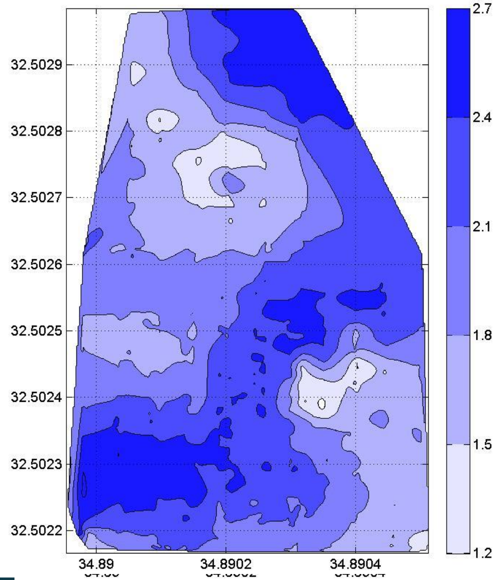
Results are presented in the form of:

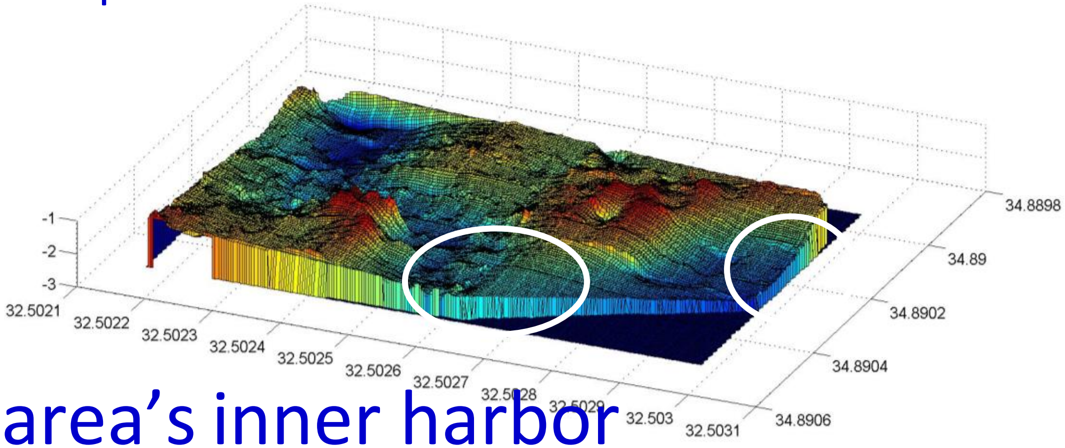
- Micro bathymetry map
- 2.5D (3D) representation
- GIS presentation, Map overlay

Presentatons show foundations of

- a round Roman tower and
- square Crusader tower

Depth 1-3 meters





Caesarea’s inner harbor

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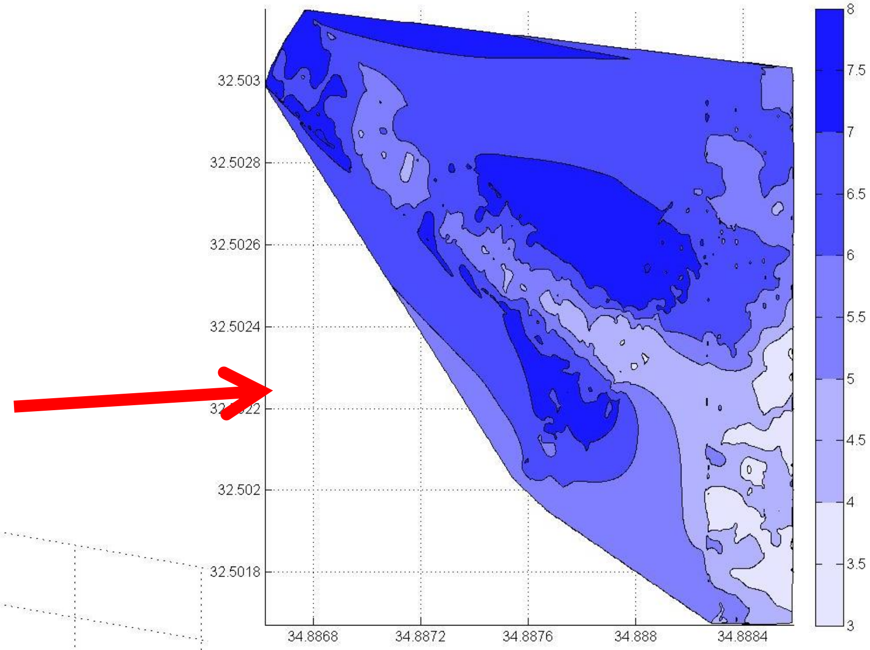
Caesarea’s outer harbor

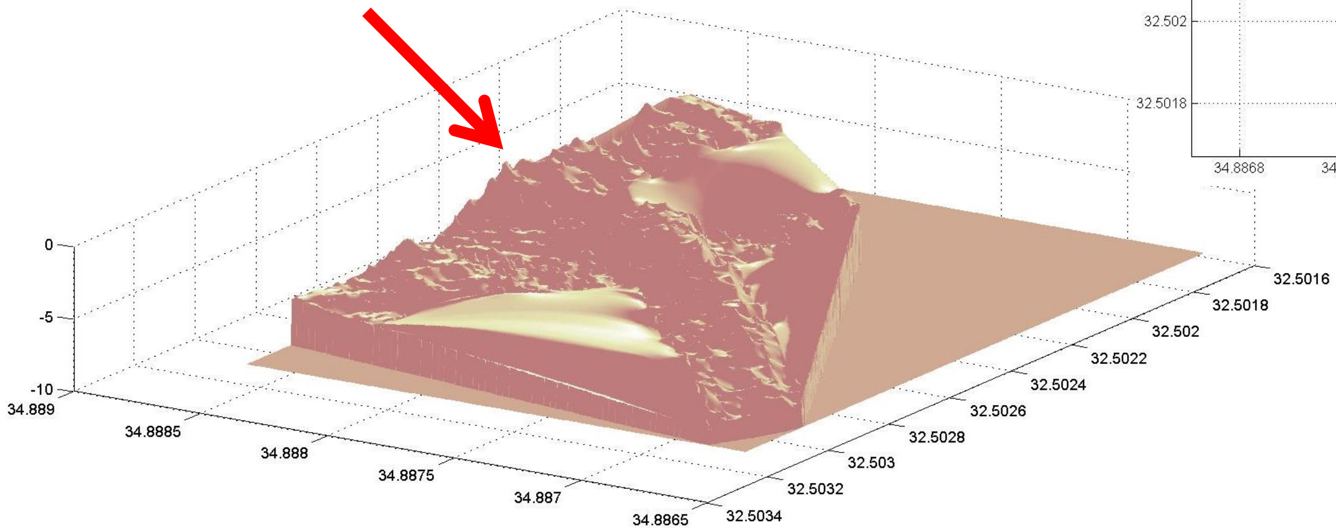
More exposed and deeper (depth 3-8 m)

Multiple mission results fused together

250 meters stretch of the submerged southern breakwater shown as:

- Microbathymetry map
- 2.5D reconstruction





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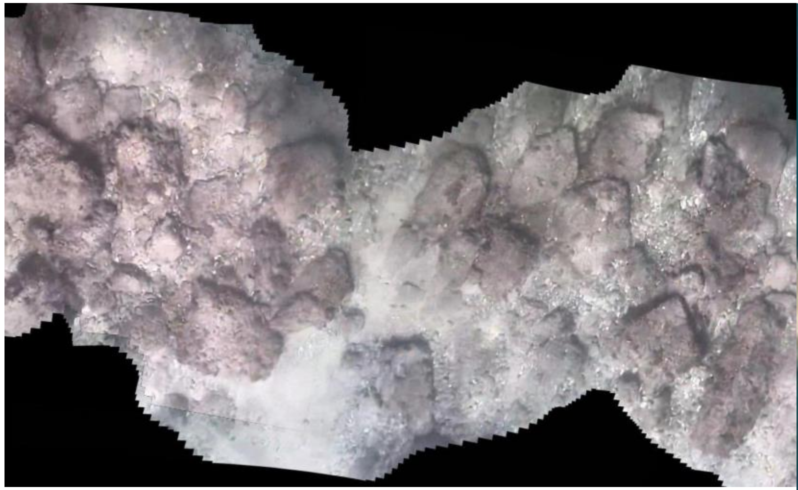
Results - Optical data

- Optical data were used to produce a photomosaic off-line
- For stitching used freely available Microsoft ICE and in-house software
- Created mosaics are aligned with the telemetry data in subsequent processing
- Images show:
- overlaid mosaic onto the map

and zoomed part of the mosaic.



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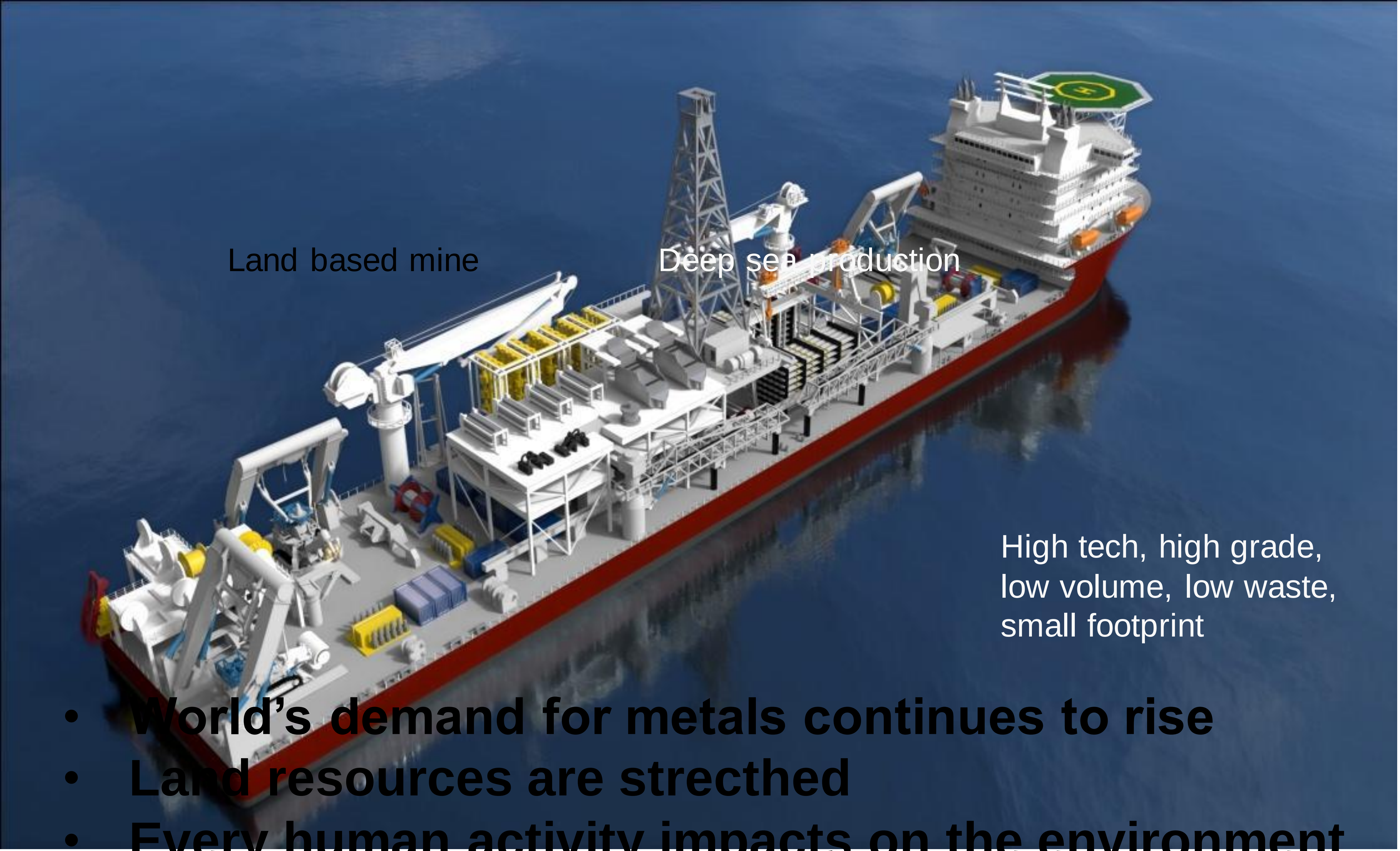
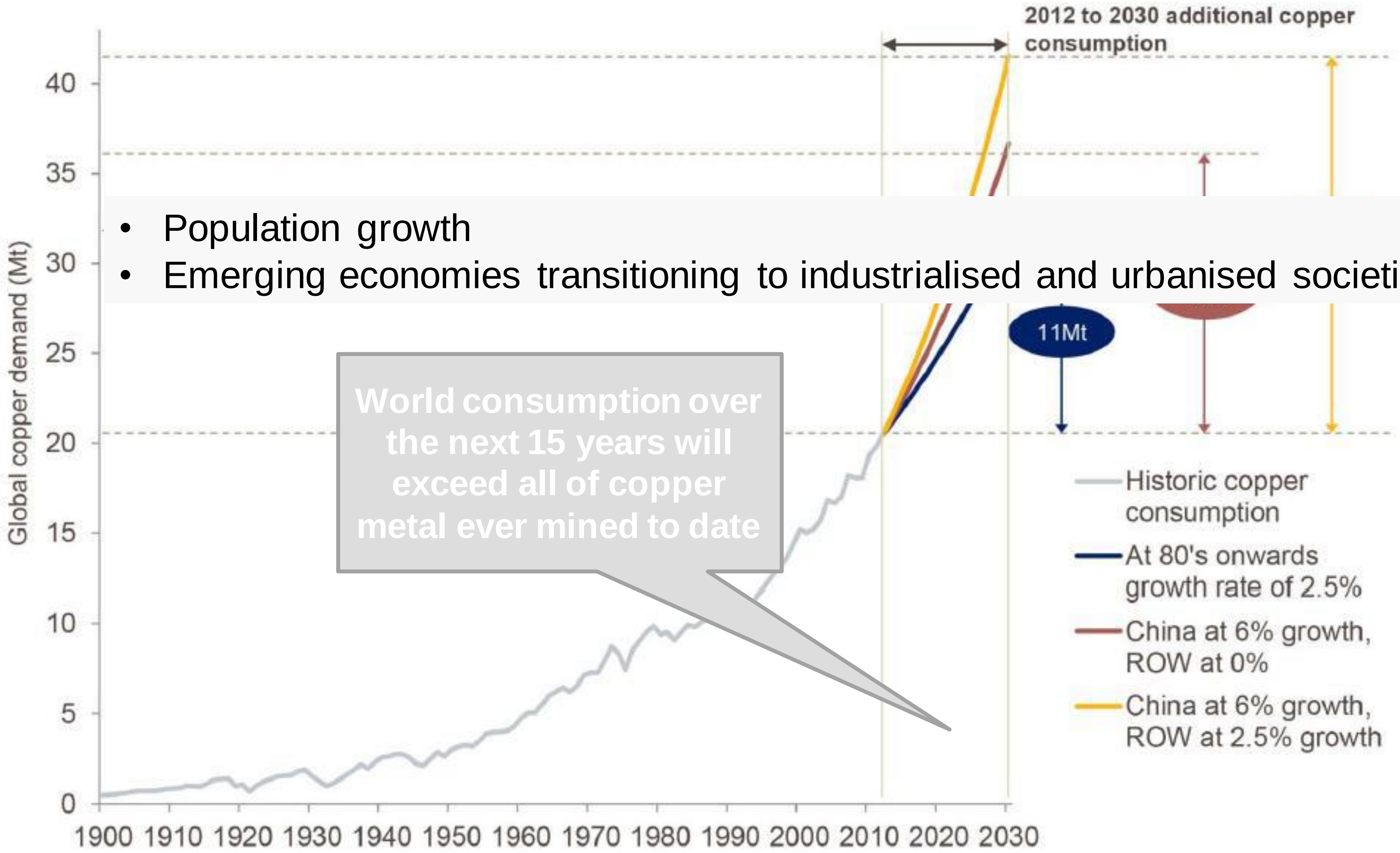
Deep sea mining



- **World’s demand for metals continues to rise**
- **Land resources are strecthed**
- **Every human activity impacts on the environment**

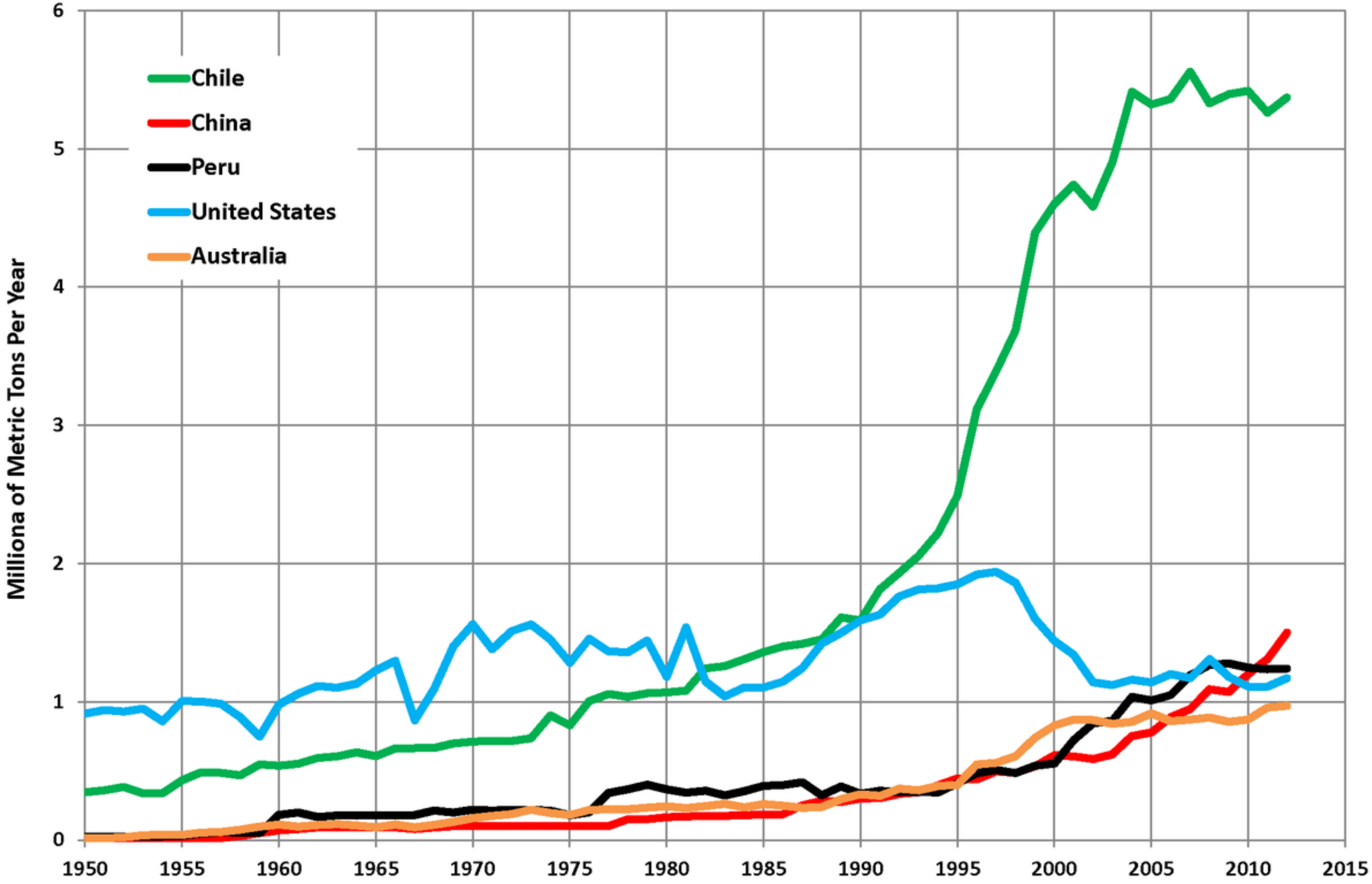
- Population growth
- Emerging economies transitioning to industrialised and urbanised societies



Source: International Copper Study Group, Glencore Xstrata

ROW = Rest of World

Top five copper producing nations



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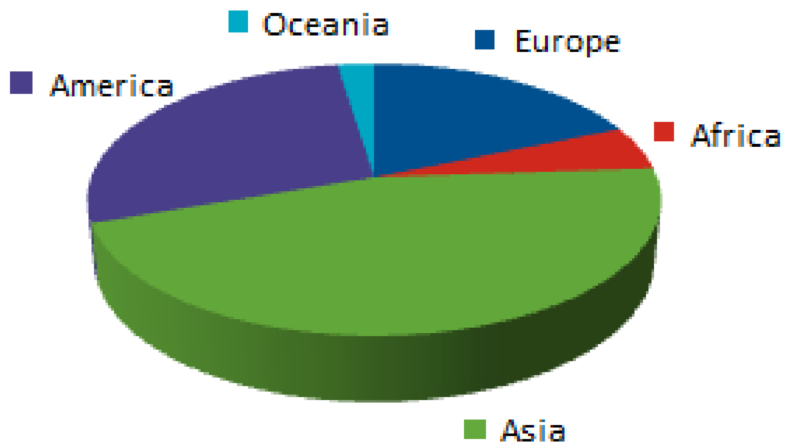
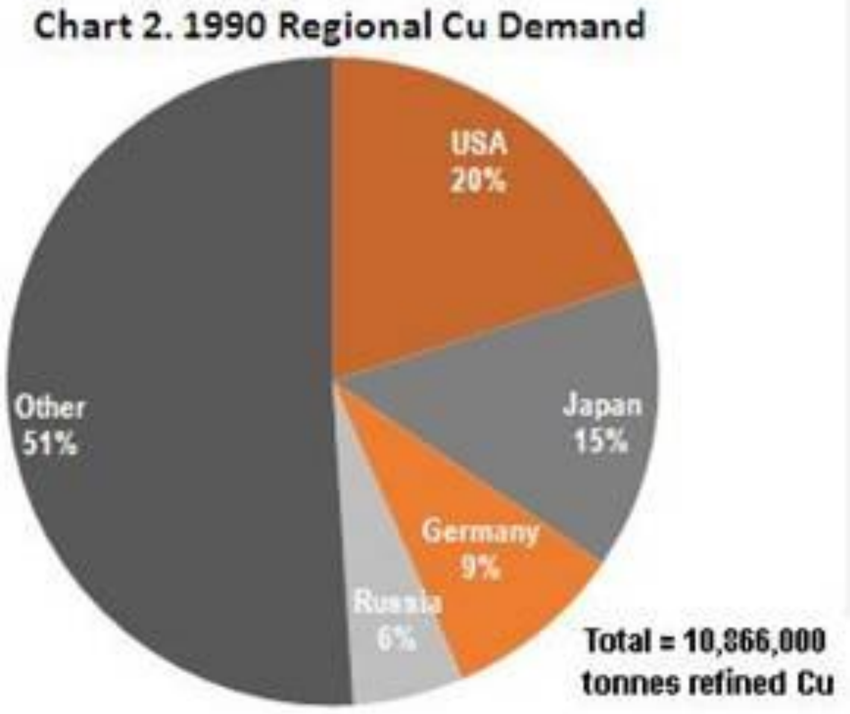
World copper production in 2011

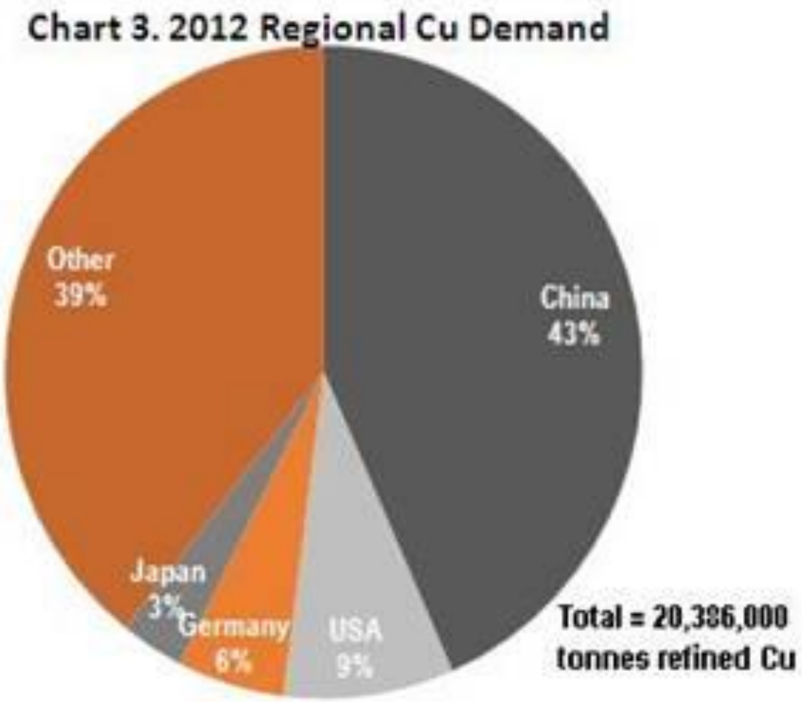


Region	%
Asia	46
America	28
Europe	19
Africa	5
Oceania	2

From London Metal Exchange

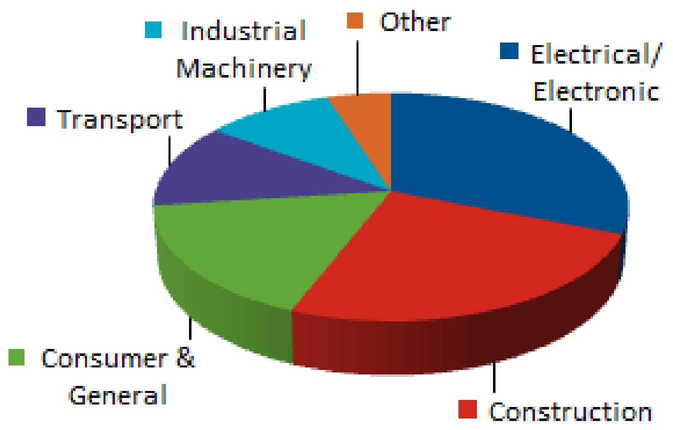
Copper Regional demand and projections



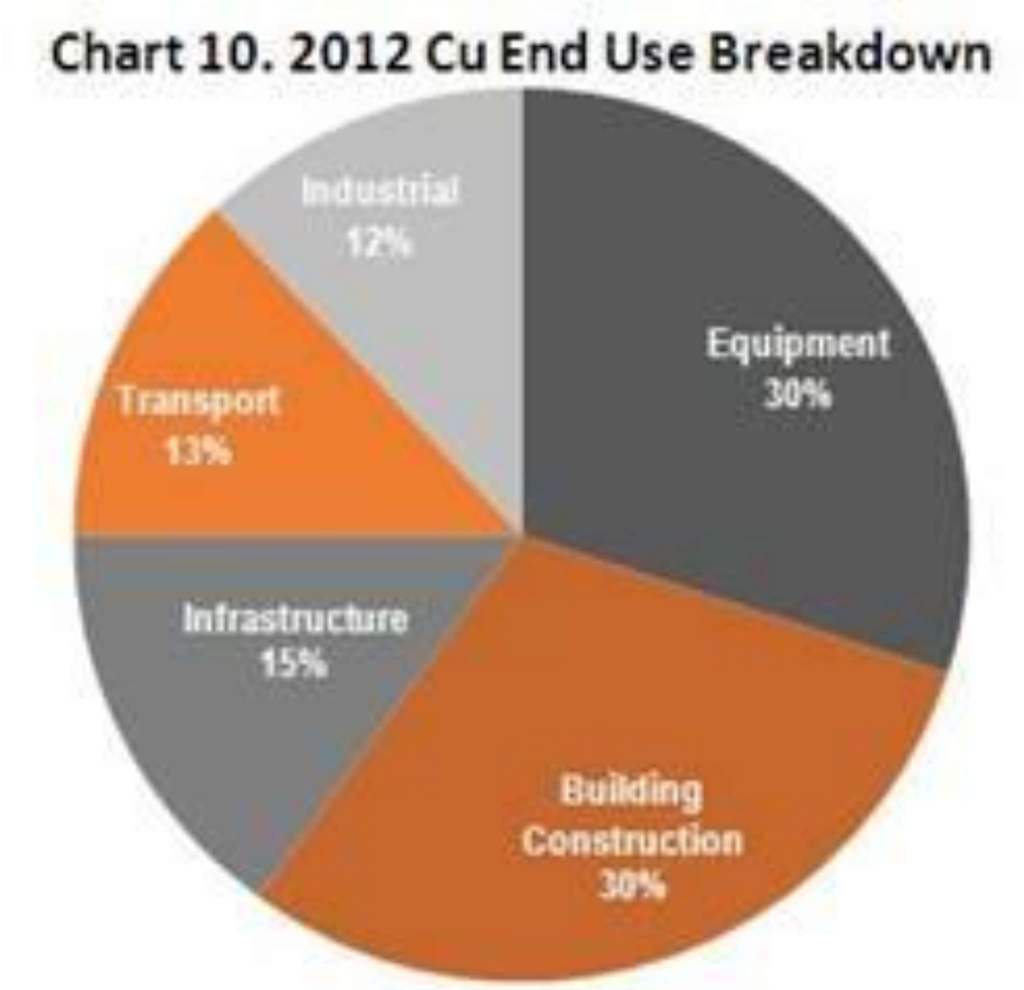


From Kitco Metals Inc.

Copper use breakdown



Market sector	%
Electrical/electronic	31
Construction	25
Consumer & General	17
Transport	12
Industrial machinery	10
Other	5



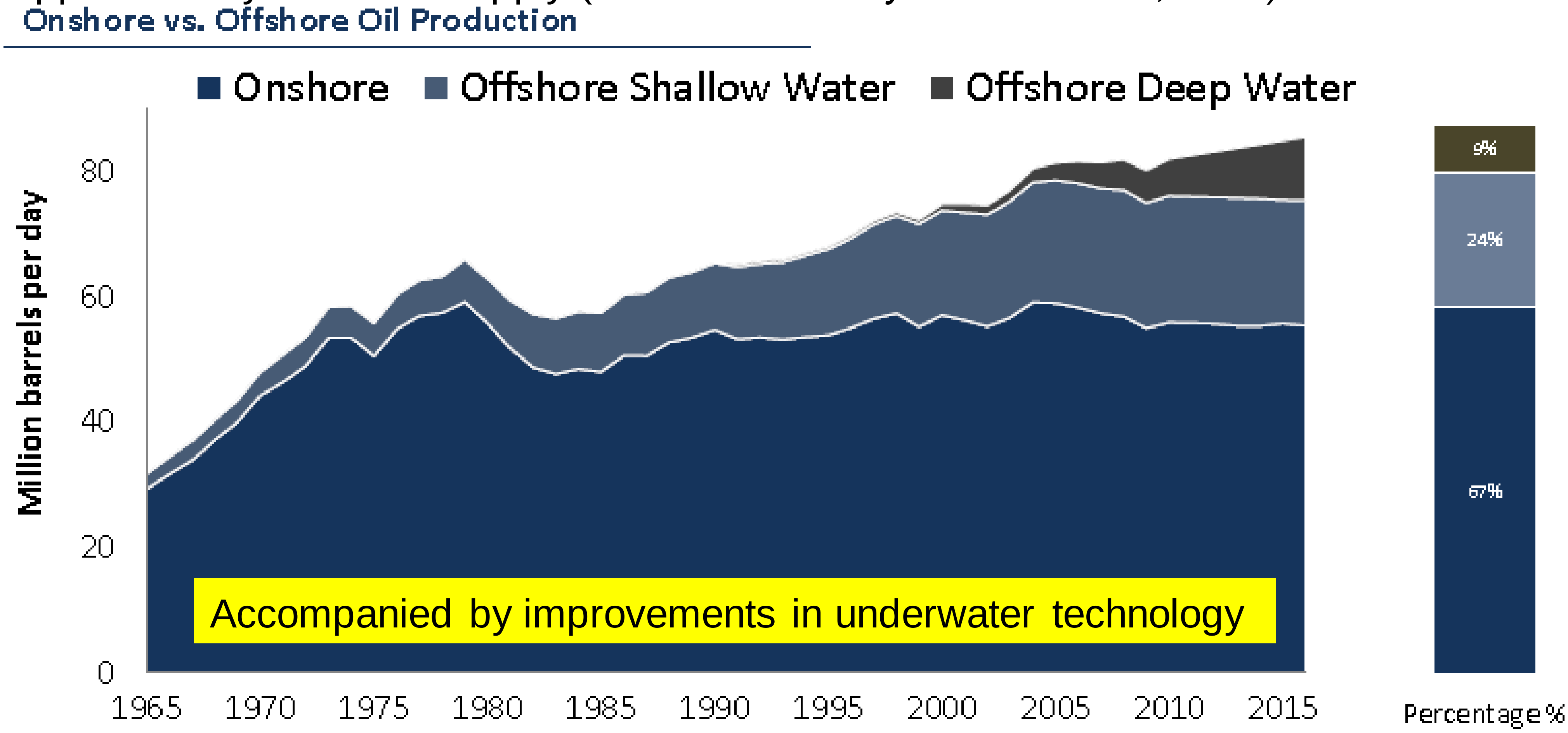
- 70% of the Earth is covered with water
- ~50% of this is in territorial waters, and ~50% in international waters
- Of the ~30% land mass, most has a water table
- Over the past 50 years there has been a gradual increase in exploration and production of various minerals offshore
- In parallel, there has been a gradual reduction in on-land ore quality/grade for key minerals and increased stripping ratios
- Demand for minerals (both for energy and industrial use) has increased

Advantages of sea mining

- Seafloor massive sulphide deposits – HIGH GRADES of:
  - Copper (est. ~275 mil.tones), Nickel (est. ~340 mil.tones), Cobalt (est. ~78 mil.tones)
  - Gold, Silver
  - Zinc
- No people need to be moved
- No land clearance to get to the deposit
- High grades → very little waste
- Increased worker safety (all ops are done remotely)
- Reusable equipment

Mineral extraction trends

On-shore crude oil production has plateaued and off-shore has increased to approximately a third of supply (*source: Infield Systems Limited, 2013)…*

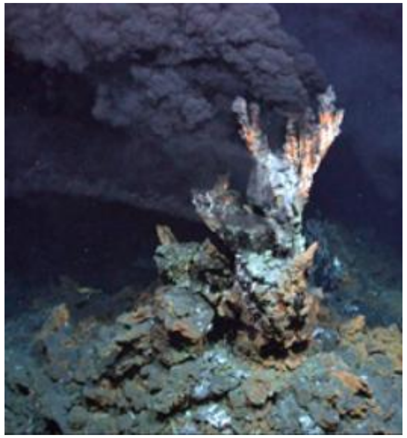


Mineral extraction trends

…enabling extraction of other minerals underwater

Alluvial diamonds And Au

Rock phosphate



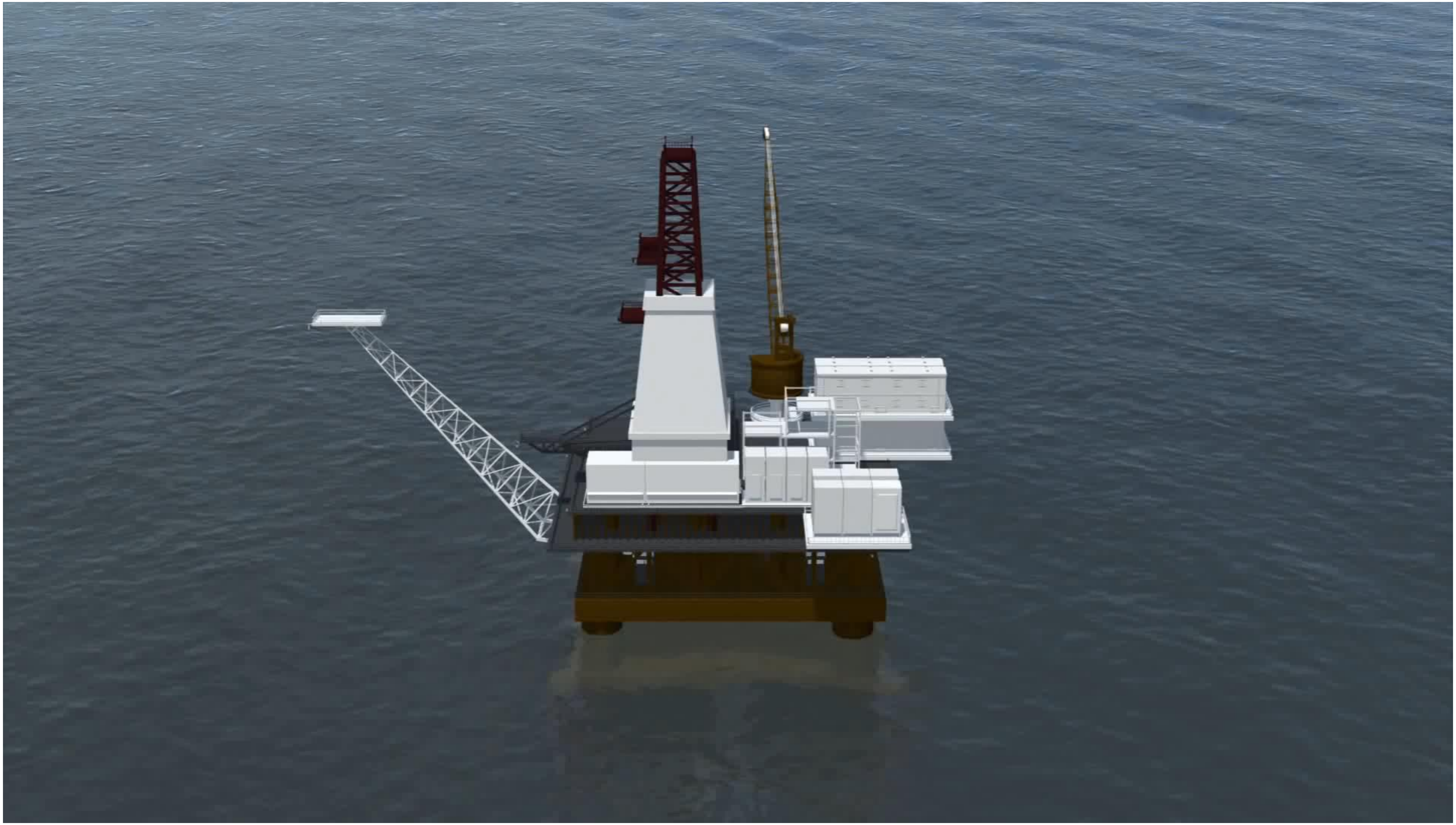
Seafloor Massive Sulfide (SMS) deposits

Ferro-manganese crusts

Polymetallic nodules

- Substantial uncovered resources from zero to 6000m depth
  - From zero to minimal stripping ratio
  - Some of these are very high grade
- And even more unexplored buried resources at sea

How deep-sea mining works



Lokheed-Martin deep sea mining project

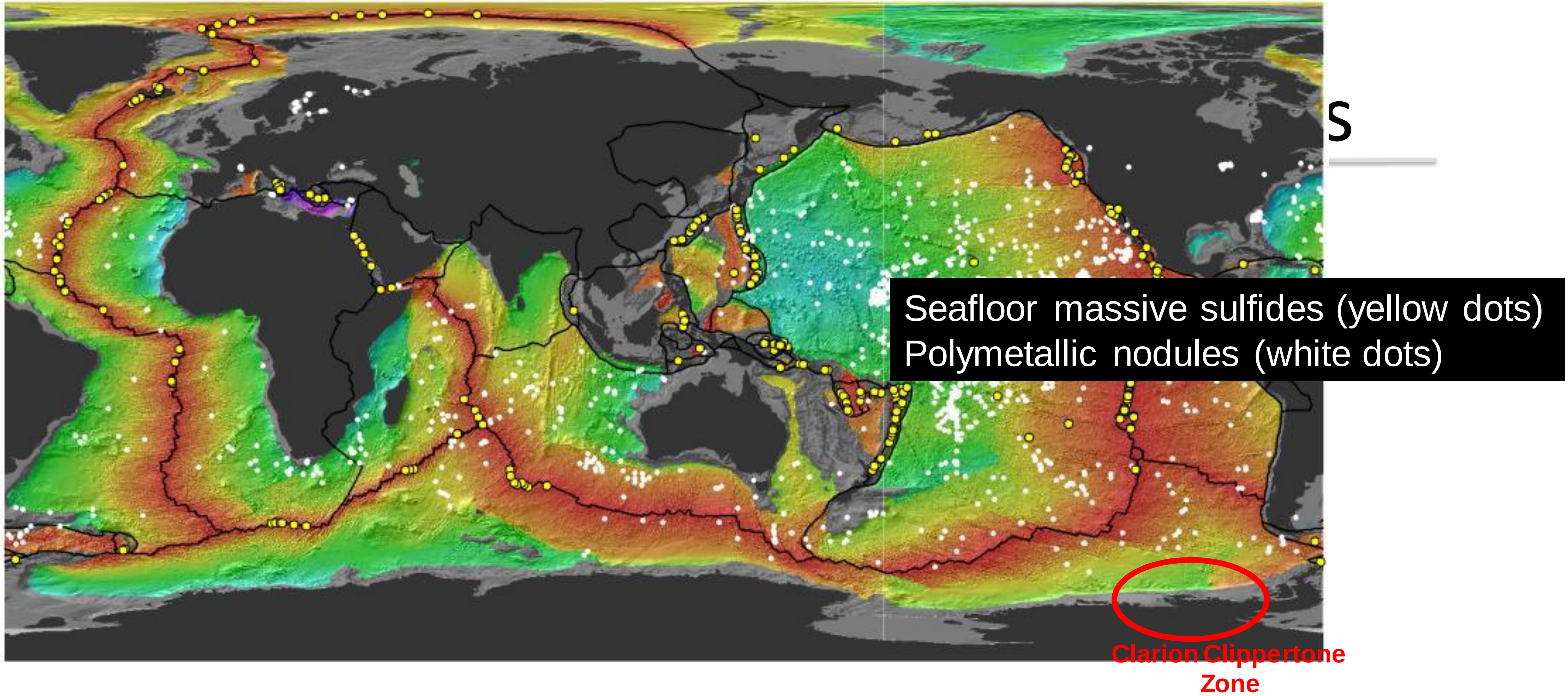
Nickel and Copper essential for hybrid batteries

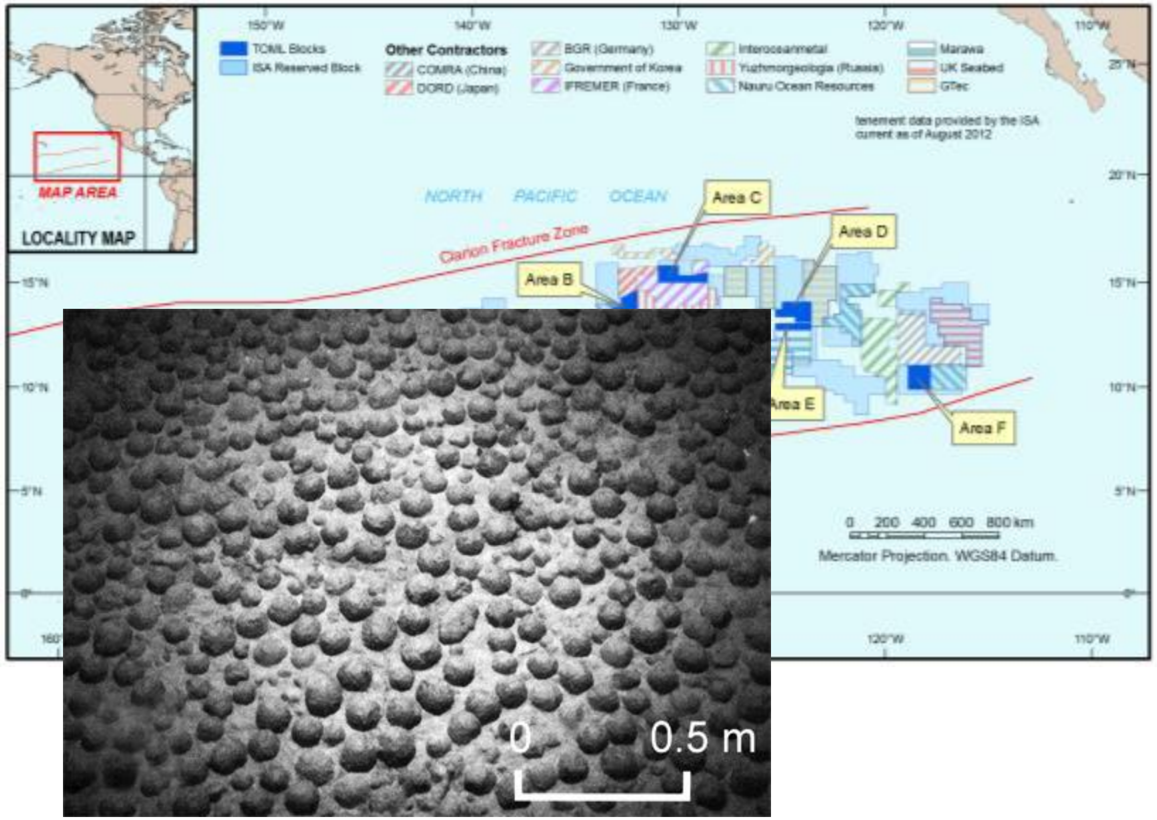
A single 2MW Wind turbine:
2 to 6 tonnes copper

An electric car contains ~2km of copper wiring

Social and environmental advantages of deep sea mining

- Seafloor Massive Sulphide (SMS) deposits – HIGH GRADES of copper, gold, zinc & silver
- Minimal overburden, which on land can be 75% of material moved
- Less ore needed to provide the same amount of metal; small physical footprint
- No indigenous or native populations to disrupt
- No blasting, no toxic chemicals, reusable infrastructure, etc.


Seafloor massive sulfides (yellow dots)
Polymetallic nodules (white dots)
Clarion Clippertone Zone

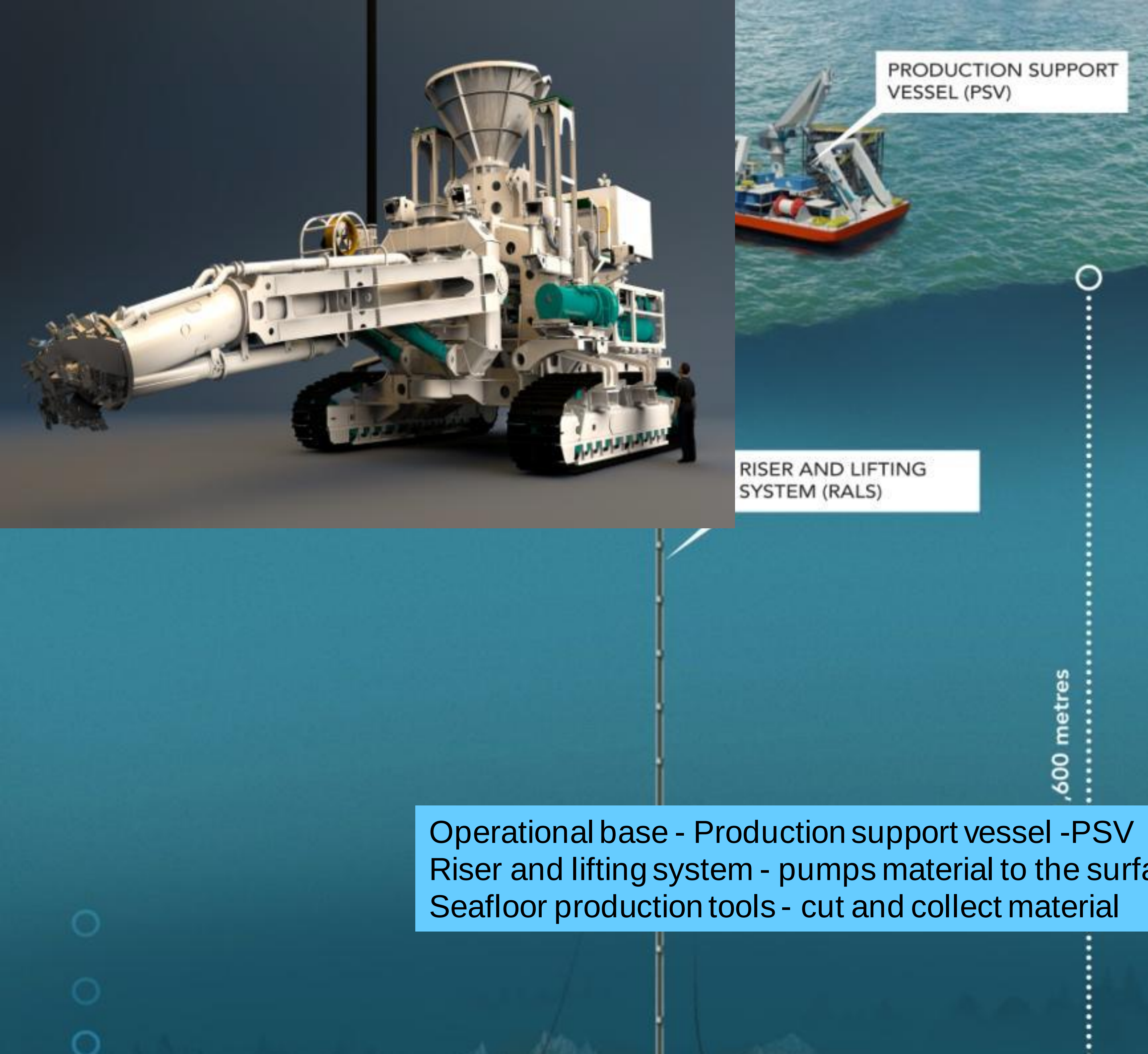


Polymetallic Nodules

Nodules lie on the seafloor at depths starting at 4,500 metres

Estimated reserves 410 million tonnes of which:

1.2% Ni, 1.1% Cu, 0.24% Co, and 26.9% Mn*



Operational base - Production support vessel -PSV
Riser and lifting system - pumps material to the surface
Seafloor production tools - cut and collect material

Increasing depth capability

Conclusion

- Advances in marine technology allow us to enhance and broaden application areas
- Some of these areas include
  - maritime security
    - safe mine neutralization
  - marine biology
    - timely detection of hazardous events
    - temporal tracking of human impact on underwater habitats
  - marine archaeology
  - deep sea mining

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Questions ?