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Investigation and risk assessment of ships loaded with chemical ammunition scuttled in Skagerrak

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CW agents produced and accumulated during WW II

Chloroacetophenone (CN)	7 100 tonnes
Diphenylchloroarsine (clark I)	1 500 tonnes
Diphenylcyanoarsine (clark II)	100 tonnes
Adamsite	3 900 tonnes
Arsine oil[1]	7 500 tonnes
Phosgene	5 900 tonnes
Sulphur-Mustard	25 000 tonnes
Nitrogen-Mustard	2 000 tonnes
Tabun	12 000 tonnes
Total (net weight)	65 000 tonnes

[1] Arsine oil: 50 % phenyldichloroasine, 35 % diphenyl-chloroarsine, 5 % triphenylarsine and 5 % trichloroarsine

Dumping in Norwegian waters

- The Norwegian authorities gave in 1945 permission to scuttle ships loaded with captured chemical ammunition on board in an area approximately 14 km X 4 km in size, 25 nautical miles south-east of Arendal
- The most likely number of ships sunk in the Norwegian part of Skagerrak is 36
- 5 wrecks were inspected in 1989
- The sea depth in this area is 600-700 metres

Investigation in 2002

- Field work to inspect some of the known wrecks
- Laboratory analysis of sediment and water samples
  - Chemical warfare agents
  - Some degradation products
  - Elemental arsenic
- Risk assessment
  - Of what we have seen
  - Theoretical release scenarios

Investigation by a ROV

- 5 wrecks were inspected in 1989
- 4 wrecks (of the previous 5) were inspected in 2002

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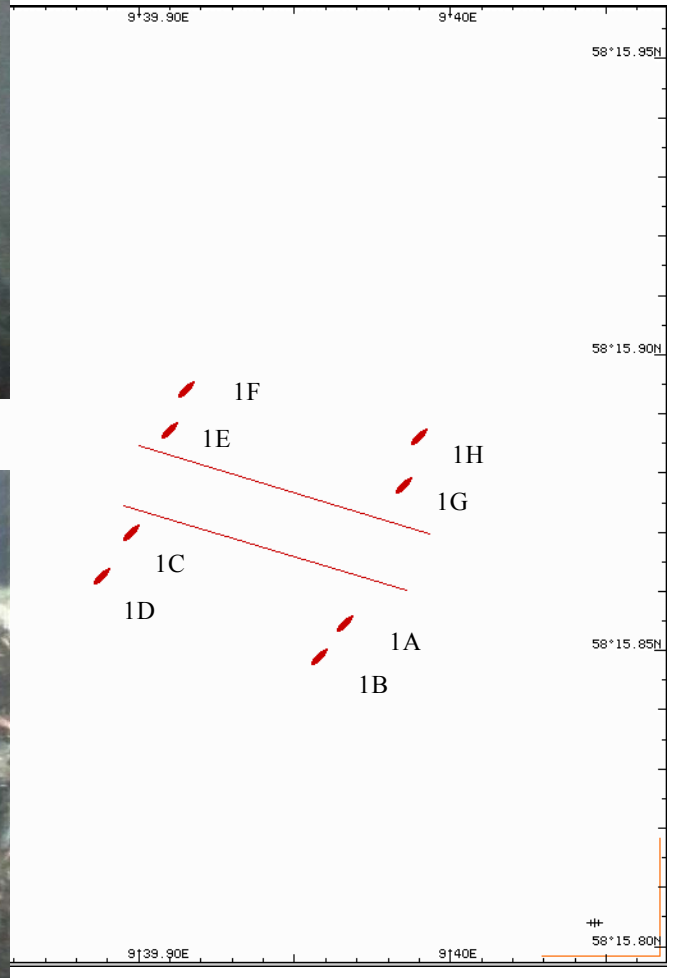
Wreck no 5



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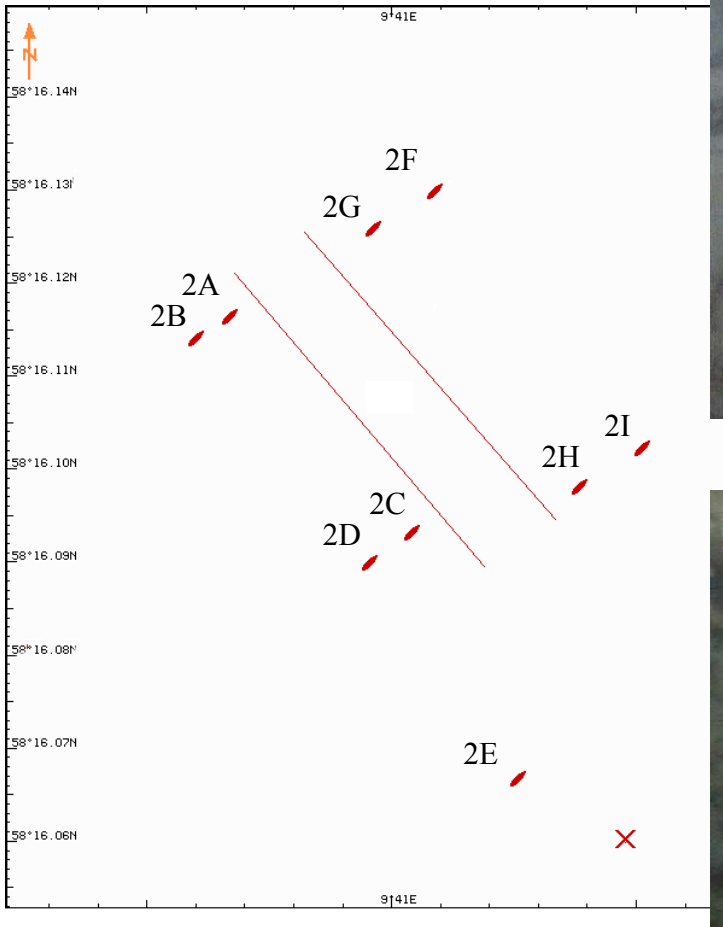
Wreck no 6



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Wreck no 6

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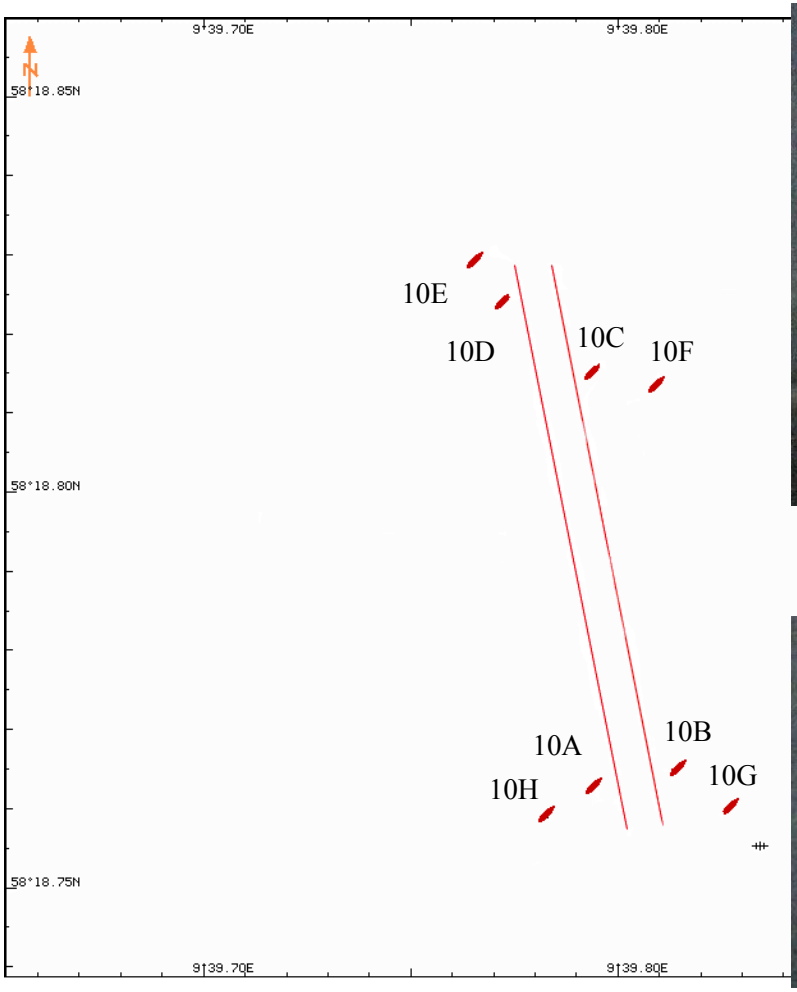
Wreck no 13



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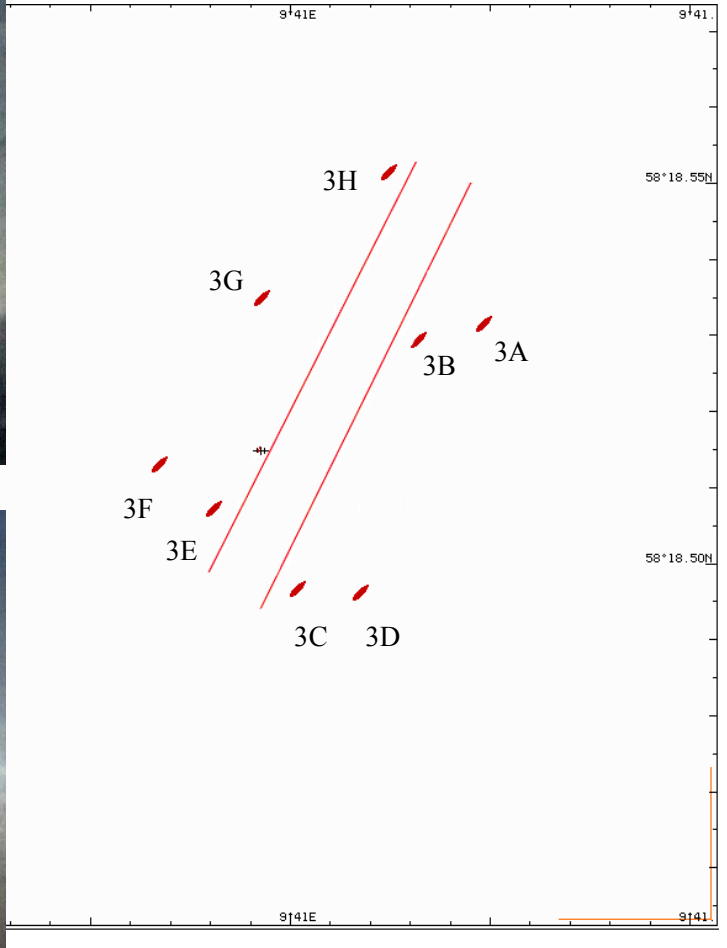
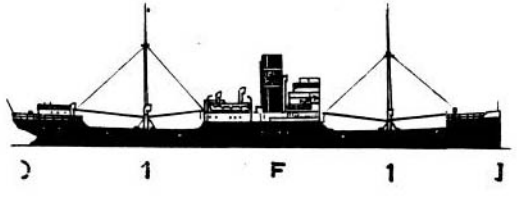
Wreck no 14 SESOSTRIS



Summary of observations

- One wreck was in several parts, the others were intact
- Aerial bombs (50 – 250 Kg) were observed in the holds and on the decks of the intact wrecks
- Aerial bombs were observed outside the damaged wreck
- Artillery shells were observed outside the wrecks
- Fishing equipment were observed hung up on the wrecks
- Abundant sea-life was observed

MEMPHIS····
SESOSTRIS···



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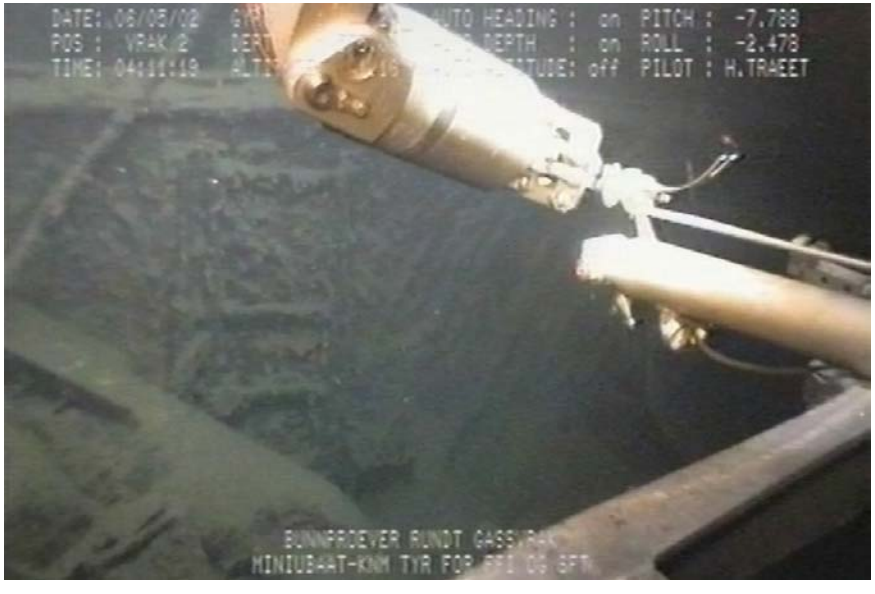
Water samples



- Nansen water-sampler
- 2 water samples per wreck
- The samples were cooled
- No chemical warfare agents or related compounds were identified
- Total arsenic was below the limit of quantification (20µg/l)

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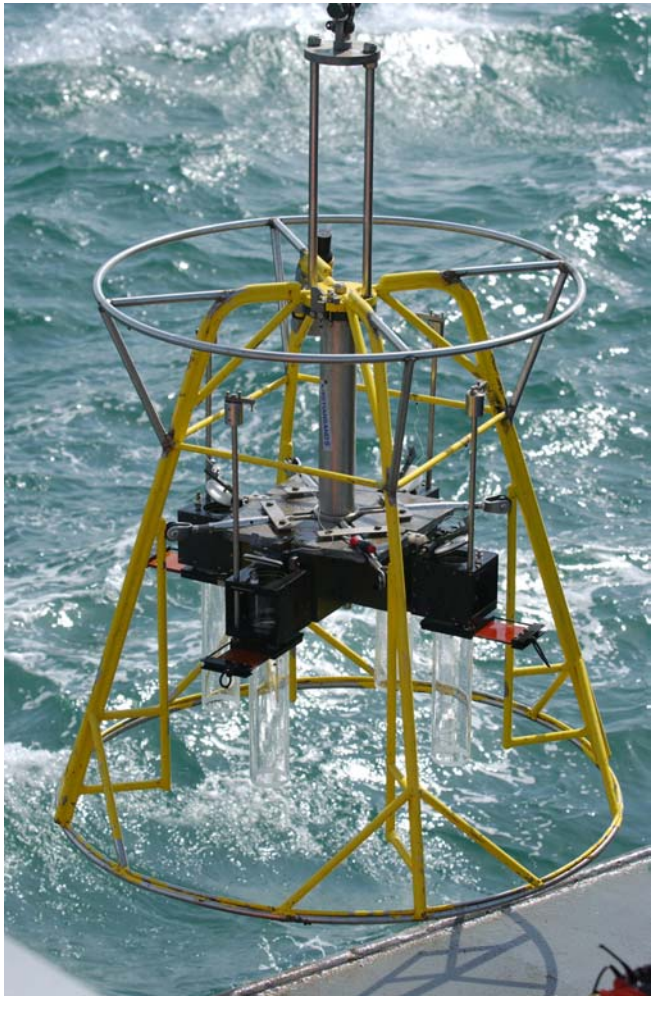
Sediment samples



- 33 different locations (+ control)
- 4 close (10-15 m) to each wreck
- 4 more distant (20-28 m) from each wreck
- 1 additional location close to one part, 50 away from wreck 6
- Two cores from each location, one sliced on board and the other core was transported back
- The samples were immediately frozen

Results from the sediment samples

Identified compounds	Found in # samples	Max amount (mg/kg dried sediment)	Lowest amount	
			(mg/kg)	S/N
Sulphur mustard (H)	1	2.4	2.4	511
TDG (bisTBDMS derivative)	(2)	weak	weak	n.m
1,2,5-Trithiephane	8	0.6	0.04	61
1,4,5-Oxadithiephane	4	0.7	0.1	160
1,4-Dithiane	3	1.1	0.2	67
1,4-Thioxane	1	1.1	1.1	258
2-chloro-1-phenyl ethanone (CN)	1	7.5	7.5	925
Clark I (DA)	21	178	0.1	84
Triphenylarsine	18	63	0.02	77
Bis(diphenylarsine oxide)	5	137	0.2	29

Results from the sediment samples (2)

- Wreck no 5
  - Sulphur mustard degradation products in 2 samples
  - Arsenic containing compounds in all samples
- Wreck no 6
  - Sulphur mustard in 1 sample
  - Sulphur mustard degradation products in 4 samples
  - Arsenic containing compounds in all samples
  - Riot control agent (CN) in one sample
- Wreck no 13
  - Sulphur mustard degradation products in 2 samples
  - Arsenic containing compounds in all samples
- Wreck no 14
  - No CW agents or related compounds

Sulphur mustard toxicity

- LD_{50} (man): 4 – 7 mg/man
- Lowest published blistering dose: 6 µg/cm^2
- Slight Erythema on skin: 50 µg/cm^2
- Blistering: 250 – 500 µg/cm^2
- Maximum allowable concentration consumed at 5 litres per day for not more than 7 days: 0.2 mg/l

The concentration found in one sediment sample (2.4 mg/kg) will not have any effect

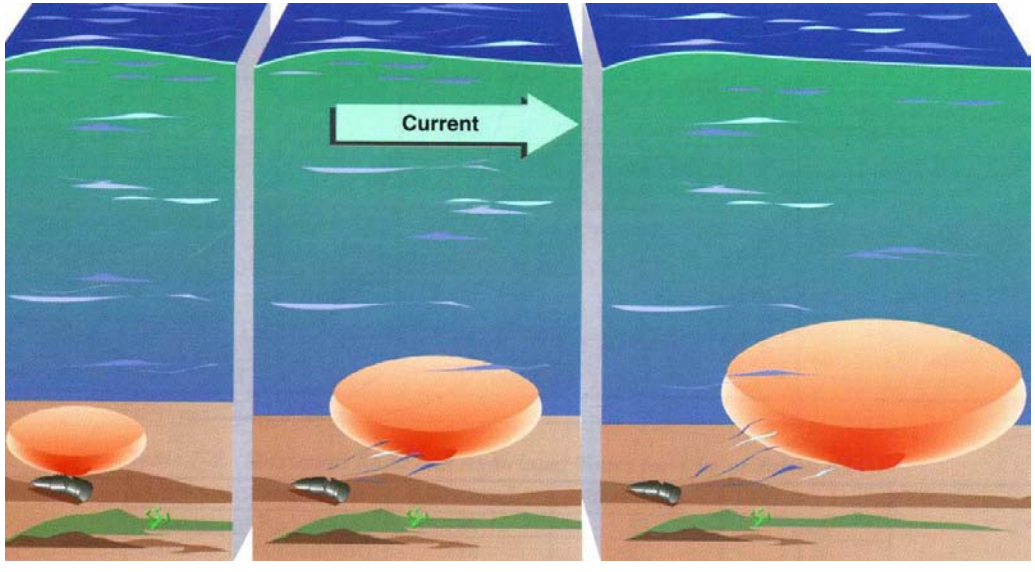
References: T C Marrs et al., Chemical Warfare Agents Toxicology and Treatment, John Wiley & Sons, 1996

Elemental arsenic in sediment samples

	I Insignificantly - little polluted	II Moderately polluted	III Markedly polluted	IV Strongly polluted	V Very strongly polluted
SFT Class (mg/kg)	<20	20-80	80-400	400-1000	>1000
No of samples	1	64	2	1	0
Wreck no	5	All	6 and 13	6	

Release of chemical warfare agents

- Release of sulphur mustard and arsenicals will only cause very local pollution due to low solubility and high density
- Release of 1 kg tabun will have a 70 m no-effect boundary
- Release of 100 kg tabun will have a 360 m no-effect boundary



Source: Medea 1997

Conclusions

- Four wrecks were inspected – little sign of corrosion
- Some ammunition was corroded and the content lost
- The wrecks had caught fishing nets
- Sulphur mustard identified in one sample + degradation products in two additional samples
- Sulphur mustard is degradable in sea water
- Arsenic containing compounds in many samples
- Arsenic is not degradable and could bioaccumulate in aquatic organisms, but the health risk associated with the current concentrations is low
- The nerve agent Tabun was not found in the samples, but could in a worst-case scenario affect a large amount of water

Recommendations

- Locate the missing wrecks – 21 wrecks might remain
- Advise against trawling in the area
- Not try to bring the ammunition to the surface
- Investigate arsenic and chemical warfare degradation products in marine organisms
- New wreck inspection within 10 years