Characteristics of non-spherical Mn nodule from the East Siberian Sea

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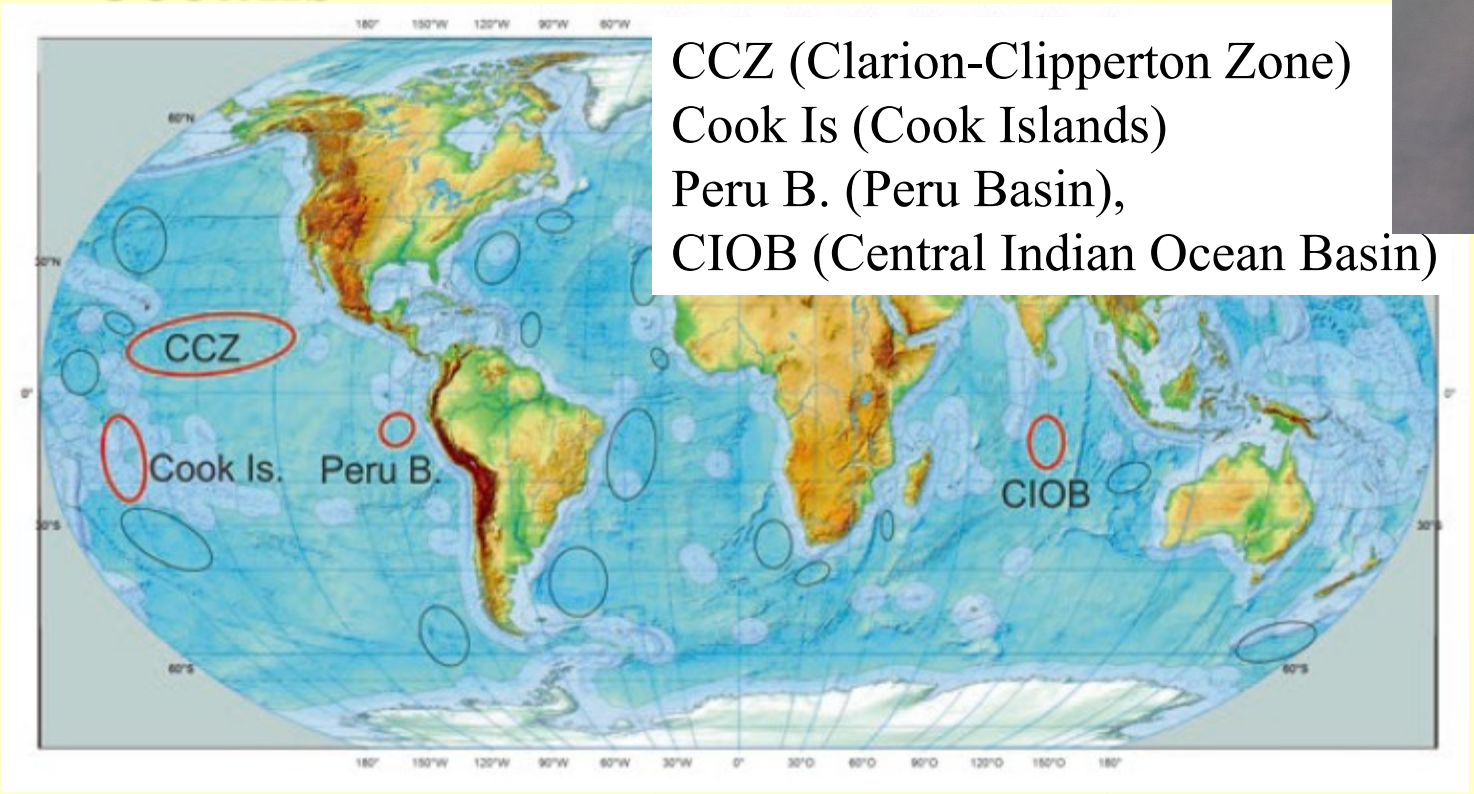
Mn Nodules

- composed mainly of Mn & Fe (Cu, Co, Ni, REE)
- form atop or within the first few cm of seafloor
- distribute in deep-sea abyssal plains of world's oceans



CCZ (Clarion-Clipperton Zone)
Cook Is (Cook Islands)
Peru B. (Peru Basin),
CIOB (Central Indian Ocean Basin)

Global occurrence of Mn nodules (Kuhn et al., 2017)

Shallow-water Mn Nodule

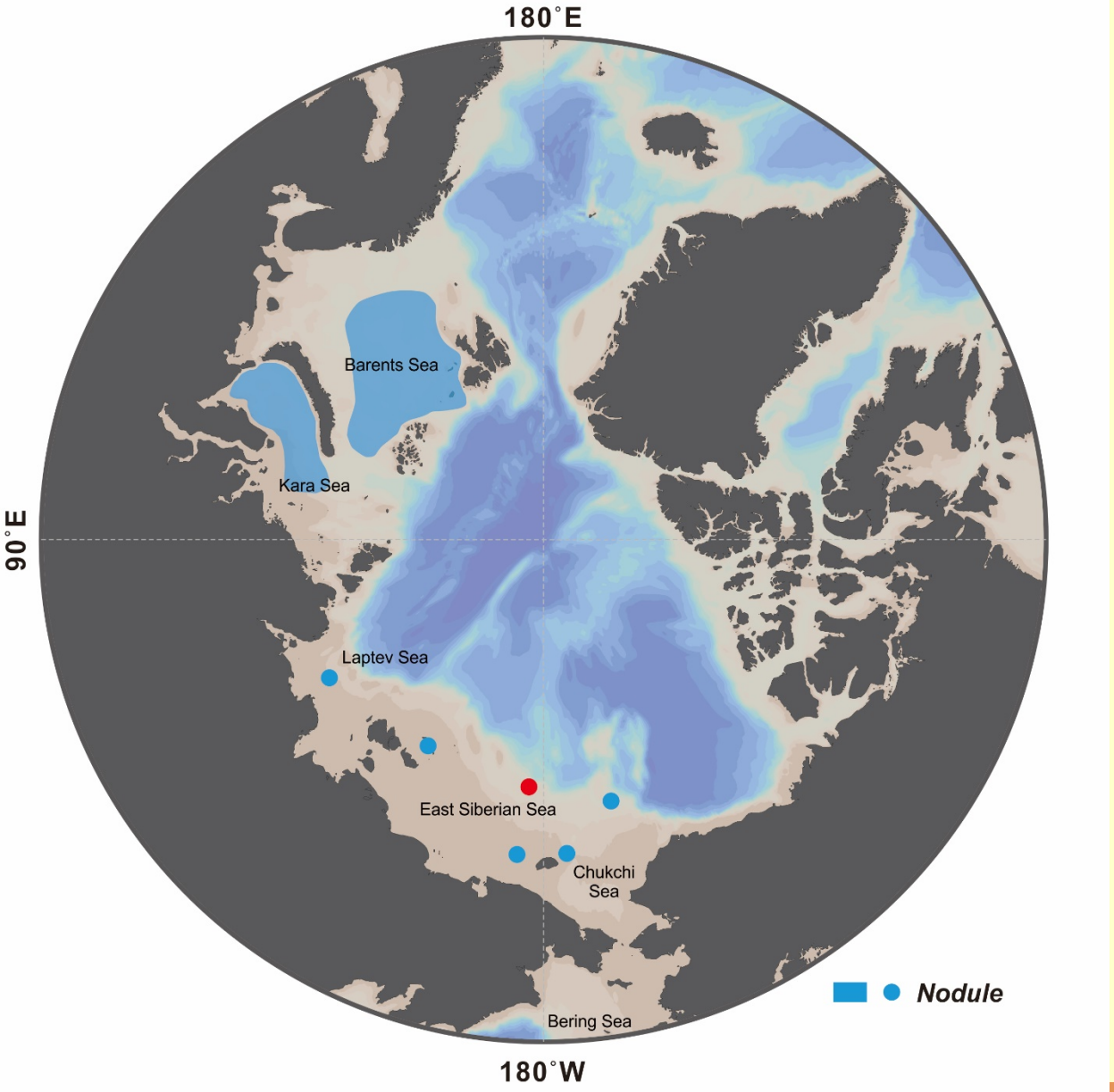
- **Mn nodules also have been recovered from the shallow-water environment (Black Sea, Baltic Sea, Arctic Ocean, few lakes)**

Fig. 1. Schematic location of basins, where ferromanganese nodules were sampled. (1) Lake Baikal; (2) Black Sea; (3) Baltic Sea; (4) Lake Krasnoe; (5) White Sea; (6) Barents Sea; (7) Kara Sea; (8) Laptev Sea; (9) East Siberian Sea; (10) Chukchi Sea.

deep-sea Mn nodule

Baturin (2019)

Mn Nodule in Arctic Ocean

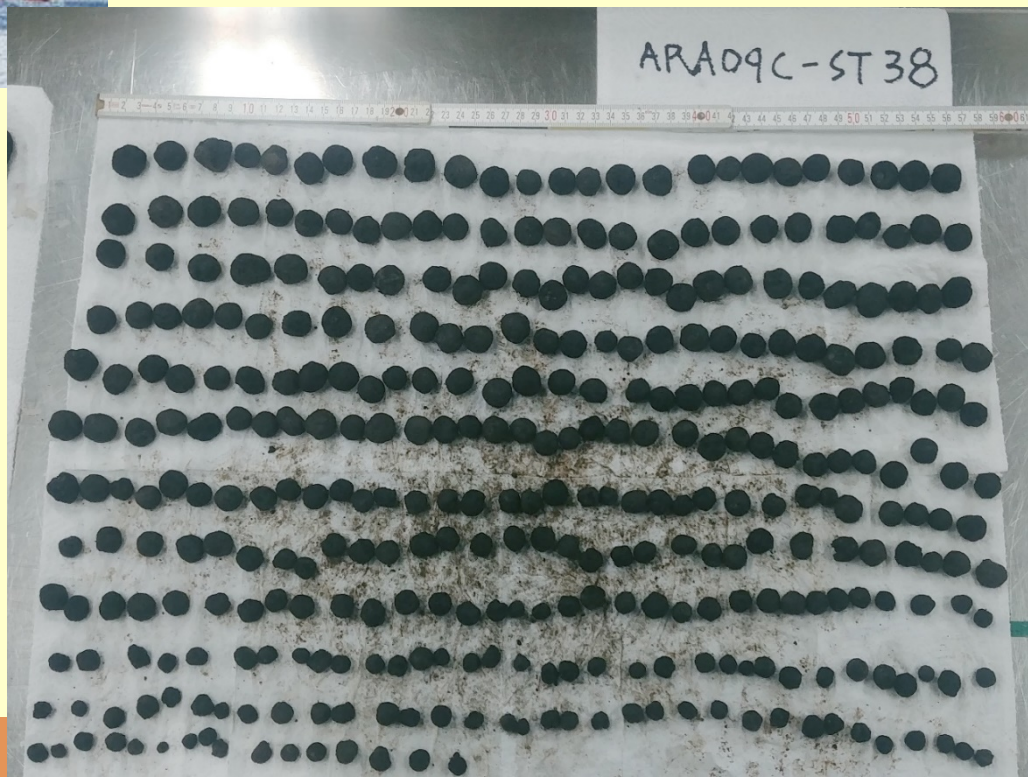


Ingri, 1985
Bogdanov *et al.* 1995
Baturin, 2011, 2019
Baturin & Dubinchuk, 2011
Kolesnik & Kolesnik, 2013
Vereshchagin *et al.*, 2019

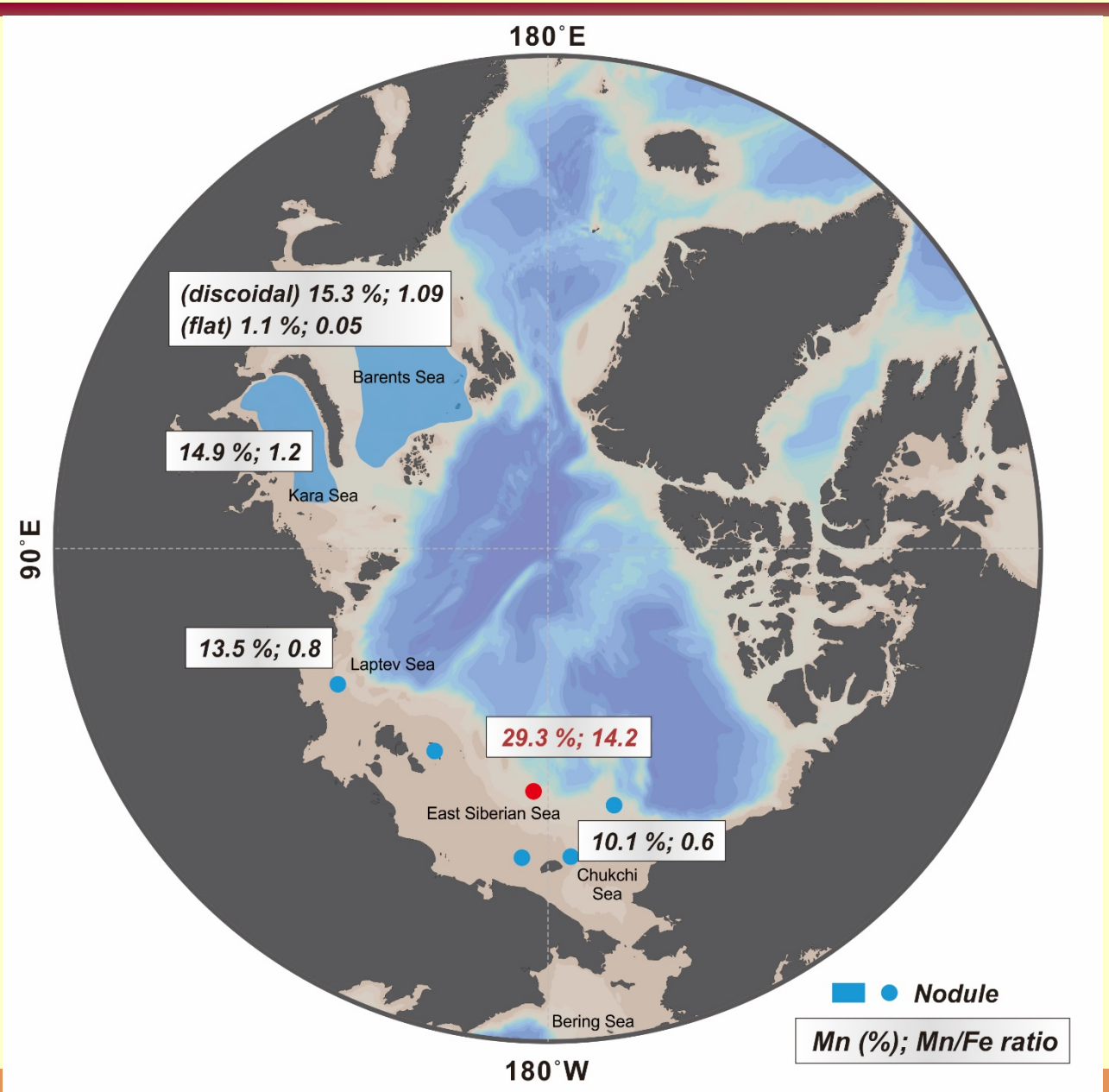
Mn Nodule in East Siberian Sea (ESS)

nearly black with spherical morphology

- 2012-2019
- 2610 ea
- 12 sites



Mn Nodule in Arctic Ocean



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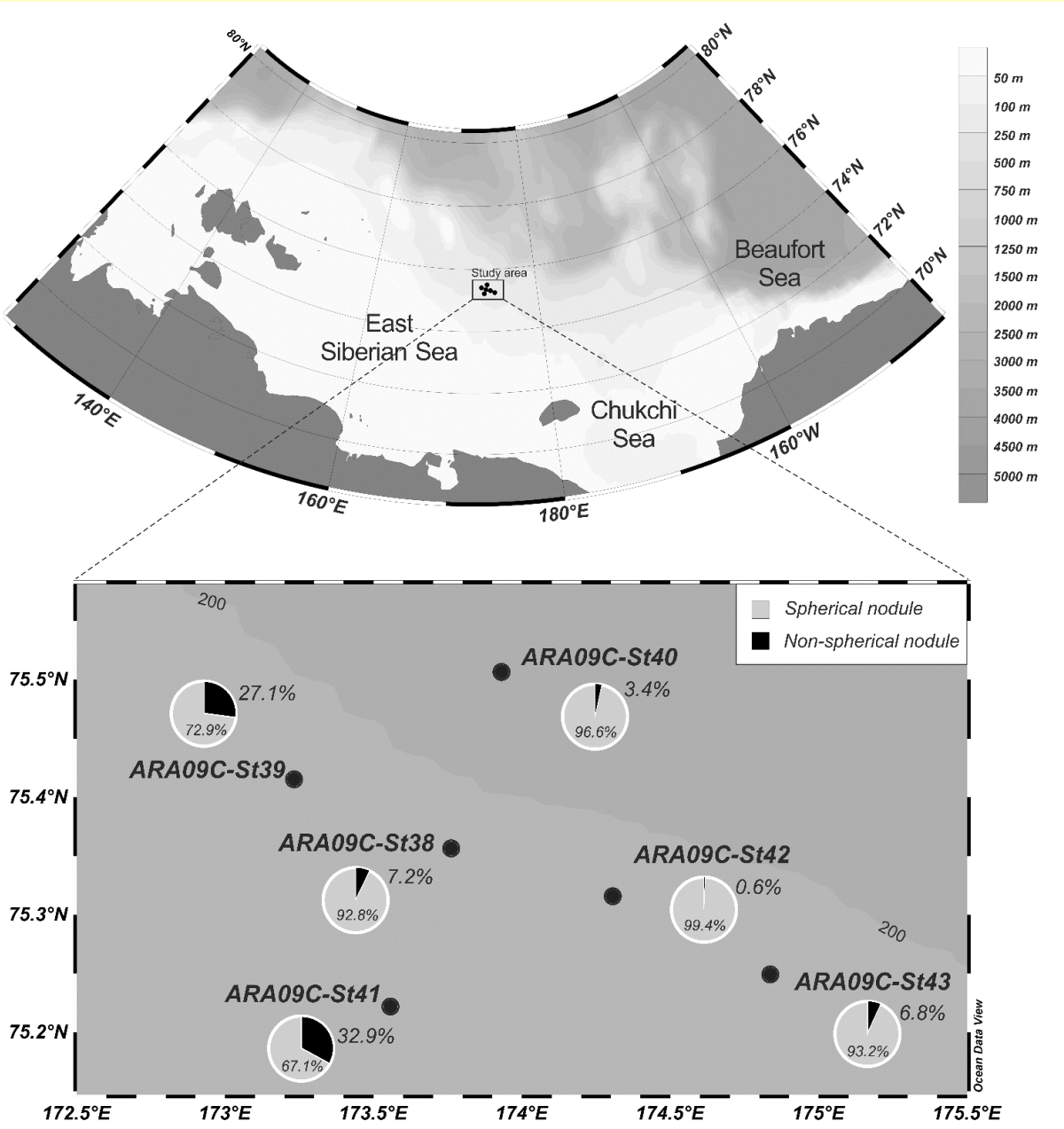
Non-spherical Mn Nodule in ESS

- ARA09C (2018)
- 6 sites
- 138/1995 ea (6.9%)



E(Ellipsoidal)-type

ARA09C-St38-358

P(Poly-nucleate)-type

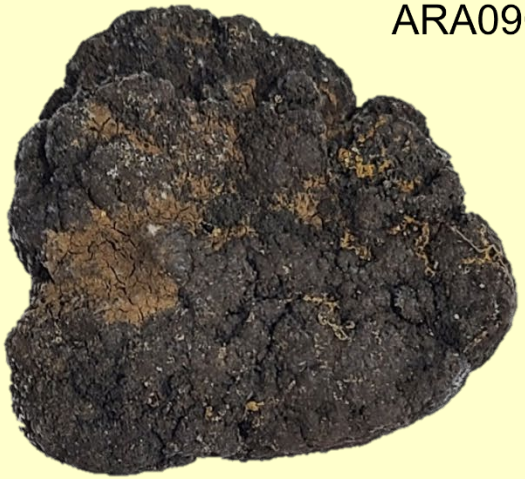
ARA09C-St39-172

Tu(Tube)-type

ARA09C-St41-162

T(Tabular)-type

ARA09C-St38-358



Side image

I(Irregular)-type

ARA09C-St42-489

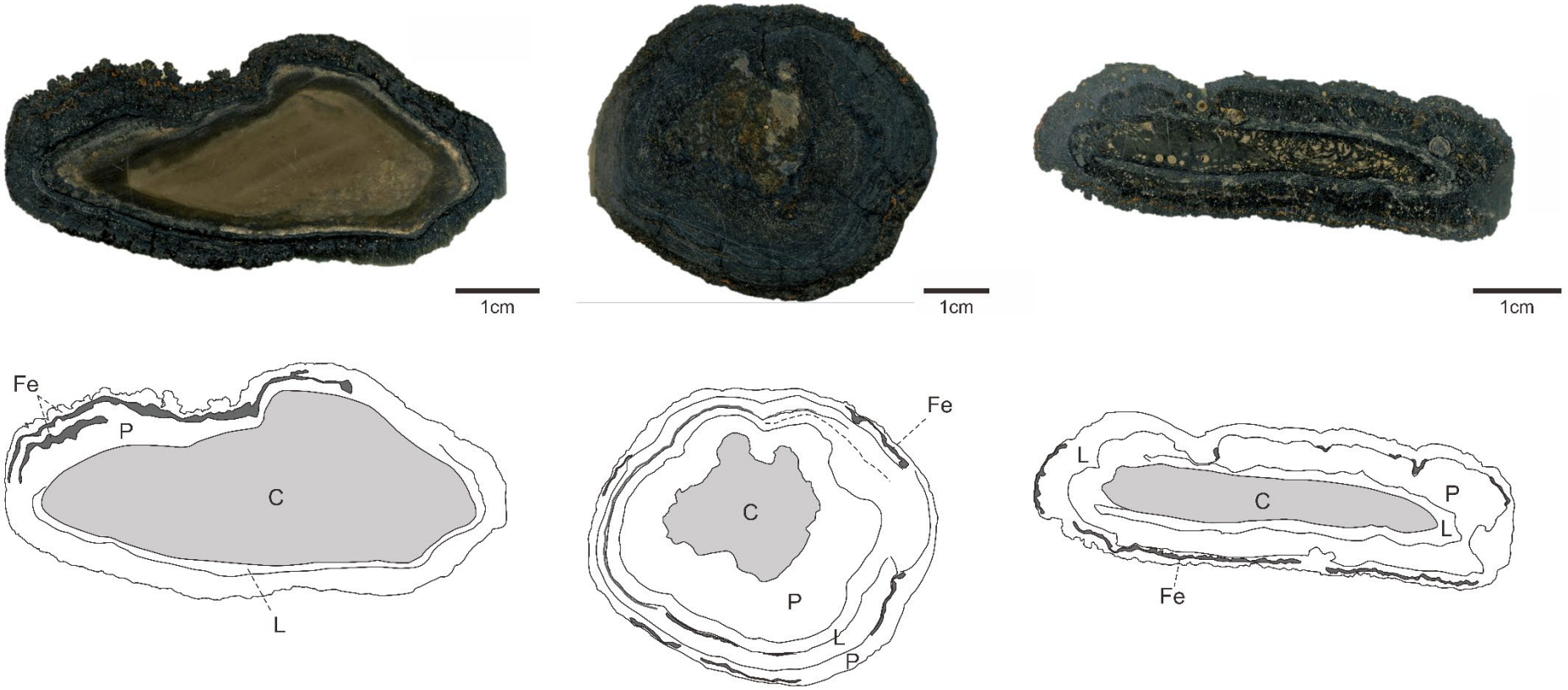
1cm

Classification of non-spherical Mn nodule

Table. Average size and weight of non-spherical Mn nodules for external shape from ESS

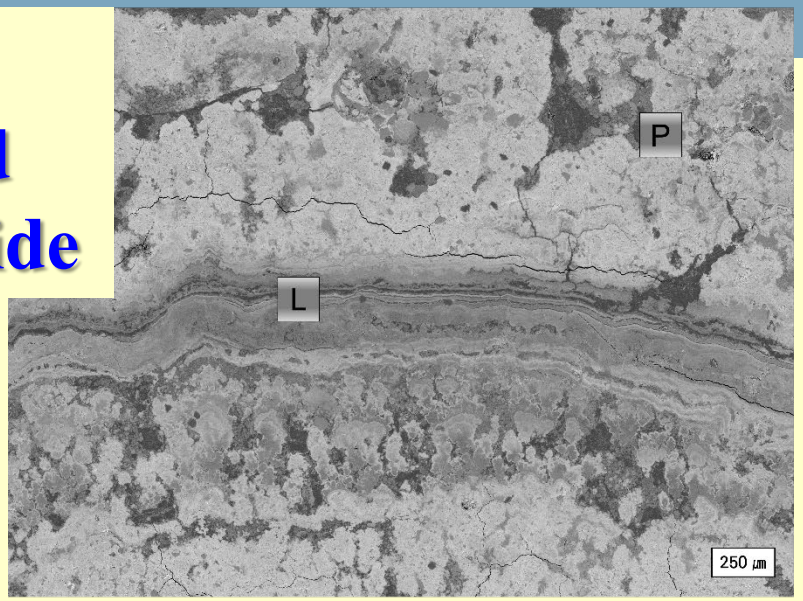
	n	Major axis (mm)	Minor axis (mm)	Weight (g)
E type	39	32.9	15.7	13.1
T type	54	42.4	14.2	26.9
P type	2	26.7	16.3	8.3
Tu type	7	36.3	14.6	9.3
I type	36	22.3	11.6	3.5
Total	138	33.9	14.0	15.7

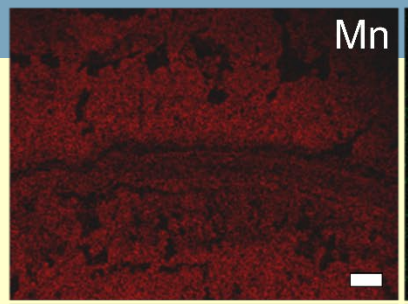
P; porous structure, L; layered structure
Fe; Fe-oxide layer, C; core

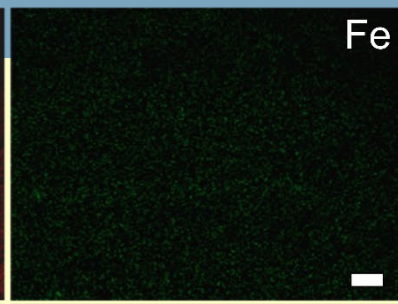


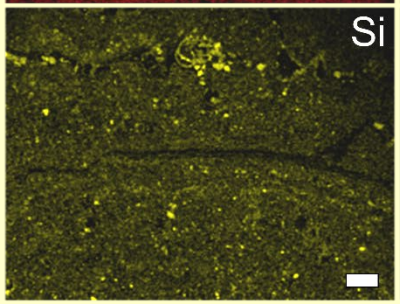
Polished-section photographs and sketches of the non-spherical Mn-nodule from the East Siberian Sea.

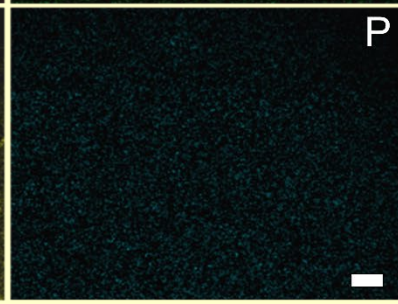
P; porous
L; layered
Fe; Fe-oxide

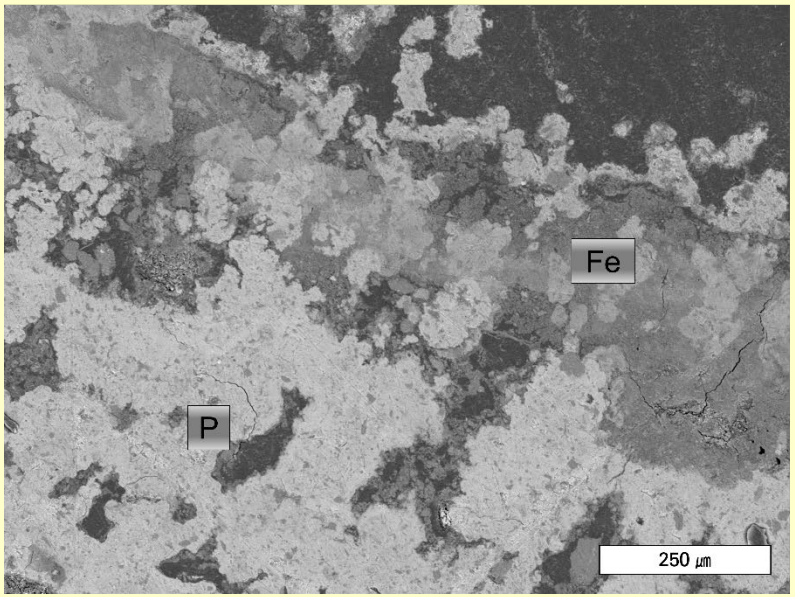


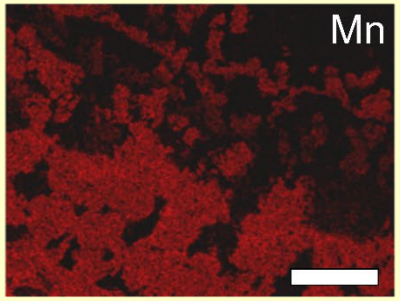


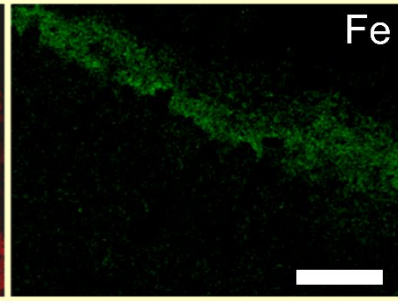


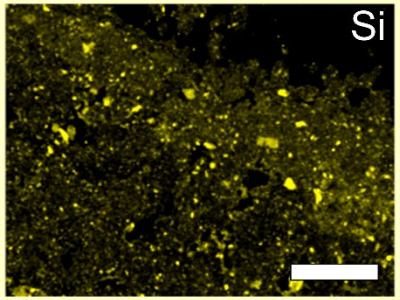


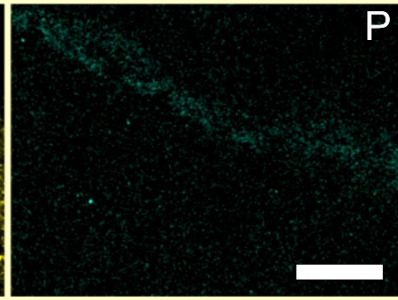






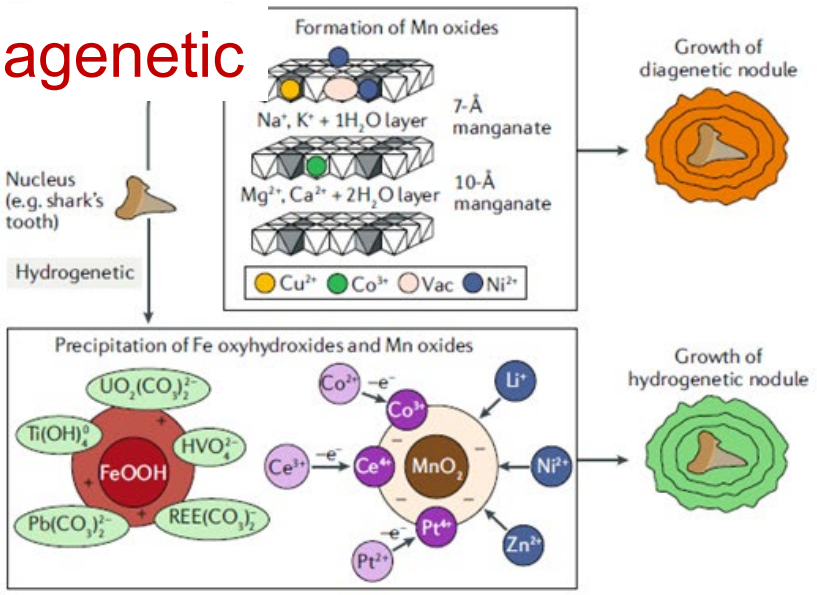






Backscattered-electron (BSE) images and elemental maps of the non-spherical Mn nodule

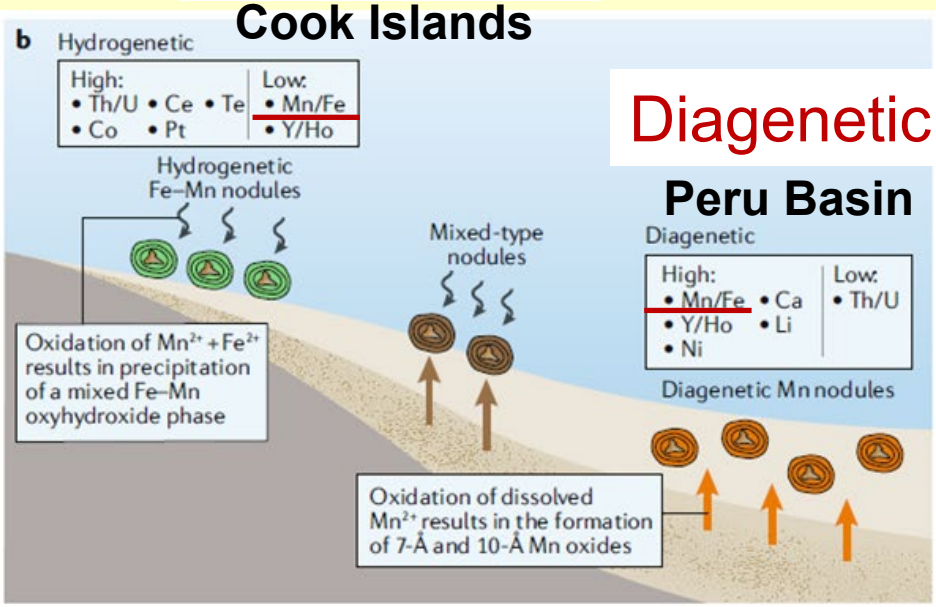
Diagenetic



Hydrogenetic

Hydrogenetic

Cook Islands



Diagenetic

Formation mechanism & geochemistry of deep-sea Mn nodule (Hein et al., 2020)

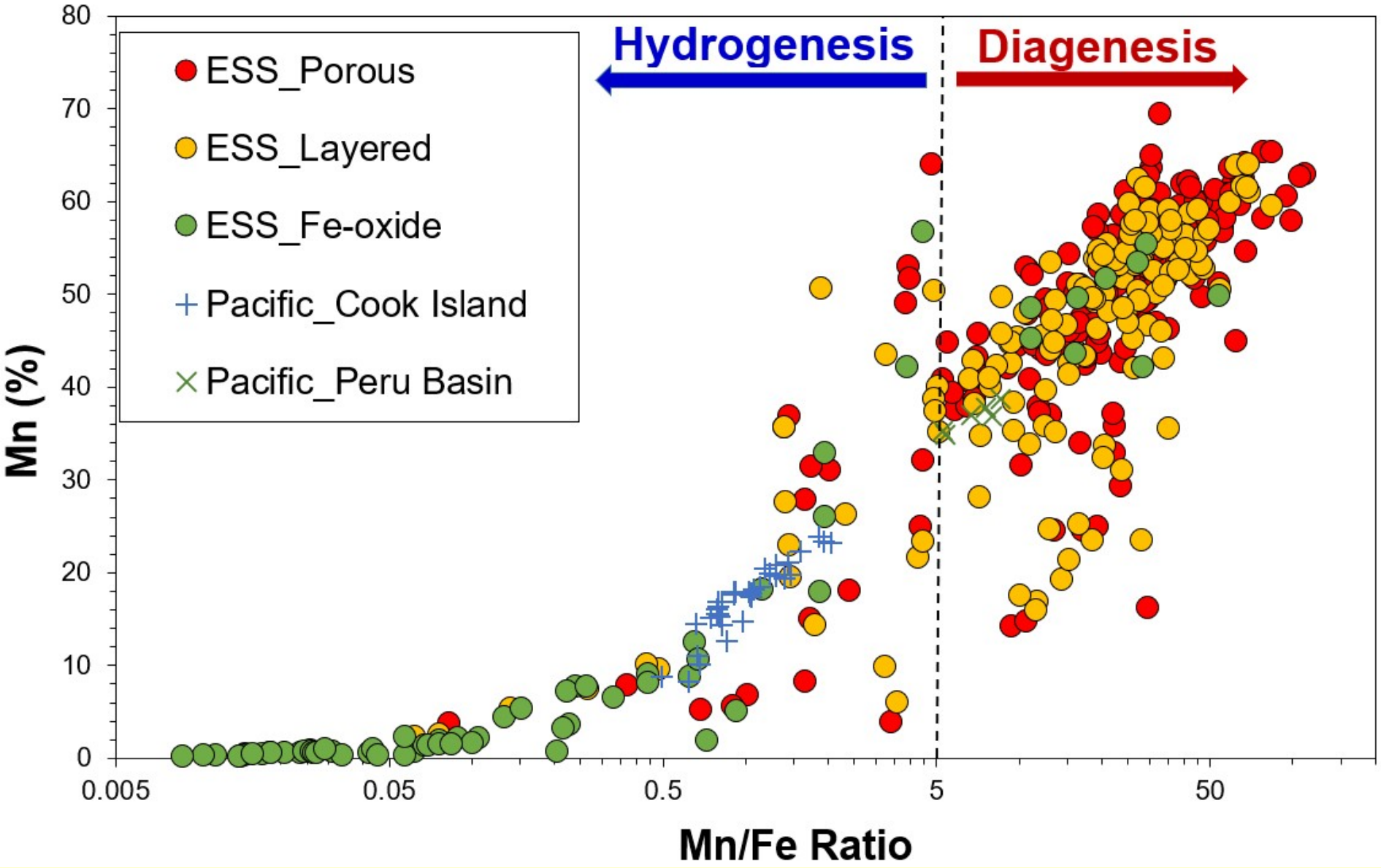
Table. Chemical composition

Seas		n	Elements (%) Mn	Fe	Si	P	Mn/Fe
East Siberian Sea (this study)	P	241	49.7	3.0	8.0	0.0	16.7
	L	144	44.0	4.6	8.9	0.2	9.6
	Fe	87	8.9	24.0	15.4	2.7	0.4
	C	90	9.9	13.7	23.8	0.1	0.7
Cook Islands[a]		36	17.1	16.9	7.9	1.4	1.1
Peru Basin[b]		6	36.8	5.5	-	-	6.9

[a]Hein et al. (2015), [b]Wegorzewski and Kuhn (2014)

P; porous structure, L; layered structure

Fe; Fe-oxide layer, C; core



Mn content vs. Mn/Fe ratio

Conclusions

- Non-spherical nodule comprises 6.9 % of total Mn nodule from the East Siberian Sea (ESS).
- Non-spherical Mn nodule can be classified into 5 types according to the external form. Tabluar type is the most abundant and the biggest and heaviest.
- The internal structure can be divided into porous structure, layered structure, Fe-oxide layer, and core. Porous and layered structure have more than 40 % Mn, and Mn/Fe ratio is 16.7 and 9.6, respectively.
- Non-spherical Mn nodule from ESS could be formed by diagenetic process.