Full title of the project (+ acronym): Mechanisms of Marine Carbon Storage and Coupled Carbon, Nitrogen and Sulphur cycles in response to global change (MCS-CNS)

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Theme / Main objectives:

- ✓ The interaction between the microbial carbon pump (MCP) and biological pump (BP) and its contribution to marine carbon storage.
- ✓ The effect of the carbon, nitrogen and sulphur cycles across the sediment-water interface and its contribution to marine carbon storage.
- ✓ The regional carbon pool in response to recent global climate change.
- ✓ The coupling of carbon, nitrogen and sulphur cycles in response to deep-time global change.

Timetable of activities: July 2016 – May 2021

2016.8; 2017.3, 2017.5, 2017.7, 2017.8; 2018.2, 2018.4, 2018.5: Project sampling cruises

2016.12; 2017.12; 2018.12: Annual academic meetings for the project

2017.6: International Conference on Geobiology organized by the PI of the project

2018.6: Mid-term evaluation of the project

Major achievements:

½ page maximum, each highlight needs to be VERY short, bullet points, with a link to publication if possible

- ✓ It is discovered that Bathyarchaeota, a widespread and abundant but poorly understood group of microbes living in marine sediments, can use inorganic carbon and obtain energy from breaking down lignin (Yu et al., 2018, PNAS), a complex molecule from plants and the second most abundant biopolymers on Earth after cellulose. The work suggested that group of Bathyarchaeota is instrumental in breaking down terrestrial carbon compounds that end up in marine sediments. Bathyarchaeota is considered one of the most abundant organisms on the planet and a common inhabitant of marine sediments, an important player in the earth's carbon cycle. The discovery that Bathyarchaeota uses lignin adds another angle to our understanding of terrestrial carbon cycling. As far as the authors are aware, this is the first report of an archaea that can metabolize lignin in anoxic marine sediments.
- ✓ The ammonia oxidization (AO) inferred by lipid biomarkers of *Thaumarchaeota* in South China Sea for the past 160 kyr exhibited intensification in the interglacials, and moreover, showed strong precessional cycles with enhancements at the precessional maxima when boreal winter insolation was the highest (Dong et al., 2019, EPSL). The ammonia oxidizing archaea (AOA) record varied in line with isotope record of organic nitrogen ($\delta^{15}N_{org}$) that is modulated by the strength of diazotroph N_2 fixation (NF), suggesting a close coupling of increased AO with enhanced NF during periods of weak east Asian winter monsoon (EAWM) and hence increase of upper water stratification. AO intensification, a step of a series of dissolved oxygen consuming processes, is hereby hypothesized to encourage NF when the EAWM weakens. This result might be a reference for the future NF trend in the current situation of enhanced ocean deoxygenation due to global warming.
- ✓ Observed monthly decline in subsurface-water pH and aragonite saturation state from spring to autumn in the North Yellow Sea (Li et al. 2018. Continental Shelf Research), and explored seasonal acidification in the Yellow

Sea (Chen et al. 2018. Science China Earth Sciences).

✓ Discovered a universal pathway for plant, fungi and bacteria to use thiosulfate as the sulfur source for growth (Chen et al. 2018. AEM), Discovered a new method to analyze sulfane sulfur which is biologically relevant (Li et al. 2019. Redox Biol).

Capacity building activities:

✓ Build enclosures at a harbor to test the carbon and sulfur cycling

List of 2018/19 publications:

1. Zhang W.*, Ni Q., Xue H. 2018, Composite eddy structures on both sides of the Luzon Strait and influence factors. Ocean Dynamics，68: 1527-1541.
2. Li C.-L., Zhai W.-D. 2018. Decomposing monthly decline in subsurface-water pH and aragonite saturation state from spring to autumn in the North Yellow Sea. Continental Shelf Research, in press. https://doi.org/10.1016/j.csr.2018.11.003
3. Zhai W.-D. 2018. Exploring seasonal acidification in the Yellow Sea. Science China Earth Sciences, 61: 647-658. https://doi.org/10.1007/s11430-017-9151-4
4. Chen Z., Zhang X., Li H., Liu H., Xia Y., Xun L. 2018. The Complete Pathway for Thiosulfate Utilization in *Saccharomyces cerevisiae*. Appl Environ Microbiol. 84(22): e01241-18. doi: 10.1128/AEM.01241-18.
5. Li H., Liu H., Chen Z., Zhao R., Wang Q., Ran M., Xia Y., Hu X., Liu J., Xian M., Xun L. 2019. Using resonance synchronous spectroscopy to characterize the reactivity and electrophilicity of biologically relevant sulfane sulfur. Redox Biol. [epub ahead of print] doi: 10.1016/j.redox.2019.101179.
6. Yu T., Wu W., Liang W., Lever M. A., Hinrichs K. U., Wang, F*. 2018. Growth of sedimentary Bathyarchaeota on lignin as an energy source. Proceedings of the National Academy of Sciences, 201718854.
7. Zhou Z., Pan J., Wang F. P., Gu J. D., Li M. 2018. Bathyarchaeota: globally distributed metabolic generalists in anoxic environments. FEMS Microbial Review 42: 639-655.
8. Dong L., Li Z., Jia G. 2019. Archaeal ammonia oxidation plays a part in late Quaternary cycling in the South China Sea. Earth and Planetary Science Letters, 509:38-46
9. Jiao N. Cai R., Zheng Q., Tang K., Liu J., Jiao F., Wallace D., Chen F., Li C., Amann R., Benner R., Azam F. 2018. Unveiling the enigma of refractory carbon in the ocean. National Science Review, doi: 10.1093/nsr/nwy020.
10. Luo G., Yang H., Algeo T. J., Hallmann C., Xie S. 2018. Lipid biomarkers for the reconstruction of deep-time environmental conditions: Earth-Science Reviews, doi.org/10.1016/j.earscirev.2018.03.005.
11. Tang K.*, Zhang Y., Lin D., Han Y., Chen C. T., Wang D., Lin YS., Sun J., Zheng Q., Jiao N.* 2018. Cultivation-Independent and Cultivation-Dependent Analysis of Microbes in the Shallow-Sea Hydrothermal System off Kueishantao Island, Taiwan: Unmasking Heterotrophic Bacterial Diversity and Functional Capacity. Frontiers in Microbiology, 9: 279.
12. Xie S. 2018. The shift of biogeochemical cycles indicative of the progressive marine ecosystem collapse across the Permian-Triassic boundary: An analog to modern oceans. Science China: Earth Science, .https://doi.org/10.1007/s11430-017-9207-3
13. Xie* W., Luo H., Murugapian S.K., Dodsworth J.A., Chen S., Sun Y., Hedlund B.P., Wang P., Fang H., Deng M., Zhang* C. L. 2018. Localized high abundance of Marine group II archaea in the subtropical Pearl River Estuary: implications for their niche adaptation. Environmental microbiology, 20(2): 734-754.
14. Yu T, Li M, Niu M, Fan X., Liang W. Wang F. 2018. Difference of nitrogen-cycling microbes between shallow bay and deep-sea sediments in the South China Sea. Applied Microbiology and Biotechnology, 2018, 102(1): 447-459.
15. Zhu X., Jia G., Mao S., Yan W. Sediment records of long chain alkyl diols in an upwelling area of the coastal

northern South China Sea. Organic Geochemistry, 121: 1-9.
16. Wu Z., Liu B., Escher P., Kowalski N., Böttcher M.E. 2018. Carbon diagenesis in different sedimentary environments of the subtropical Beibu Gulf, South China Sea. Journal of Marine Systems, 186: 68–84.
17. Zhang *C.L., Dang H.Y., Azam F., Benner R., Legendre L., Passow U., Polimene L., Robinson C., Suttle C.A., Jiao N.Z. 2018. Evolving Paradigms in Biological Carbon Cycling in the Ocean. National Science Review, https://doi.org/10.1093/nsr/nwy074.
18. Yang Y., Gao C., Dang X., Ruan X., Lv X., Xie S., Li X., Yao Y., Yang H.*. 2018. Assessing hydroxylated isoprenoid GDGTs as a paleothermometer for the tropical South China Sea. Organic Geochemistry, 115: 156-165.