An Ocean **in Space**

By Susanne Neuer, PhD (AWIS member since 1992)

I am a biological oceanographer, passionate about marine plankton and its importance for the food web of the ocean and its role in carbon dioxide uptake and carbon flux. I love doing research out in the open ocean on a research ship, far away from land, and I have been on countless research cruises. But about a decade and a half ago I experienced an unusual transition for an oceanographer. Following my husband to Arizona State University, I found myself transplanted into the midst of Arizona's desert, not where one would go looking for oceanography or any kind of marine science.

Looking back at those first years, as the proverbial 'fish out of water', they were the beginning of both a difficult and a remarkable adventure. Thankfully the adventure had a good ending; after a few years as a research faculty member, I managed to obtain a tenure track position in the then newly formed School of Life Sciences at ASU, and now run the only oceanography lab on campus. But this is not really what this story is about.

This story is about a transition that ultimately opened my eyes to the opportunities that other fields of science, even astrobiology, could offer to an oceanographer. One of the early opportunities at ASU was afforded to me by the late Ron Greeley, a founding father of planetary geology, who had been the leader of the Europa Focus Group of the NASA Astrobiology Institute. Europa is one of the four Galilean moons orbiting Jupiter. It is an icy planet in an utterly inhospitable part of the solar system where the sun is faint and too weak to warm the surface. Surface temperatures are far below even those of the coldest winter night in Antarctica. In addition, a bombardment of energetic radiation stemming from Jupiter's magnetosphere would kill any potential life-form exposed to the surface within a few seconds. But for anyone hunting for likely habitats of possible life-forms outside our own planet Earth, it is probably amongst the most exiting planetary bodies in the solar system.

It is an icy moon in an utterly inhospitable part of the solar system where the sun is faint and too weak to warm the surface.

Image Credit: NASA

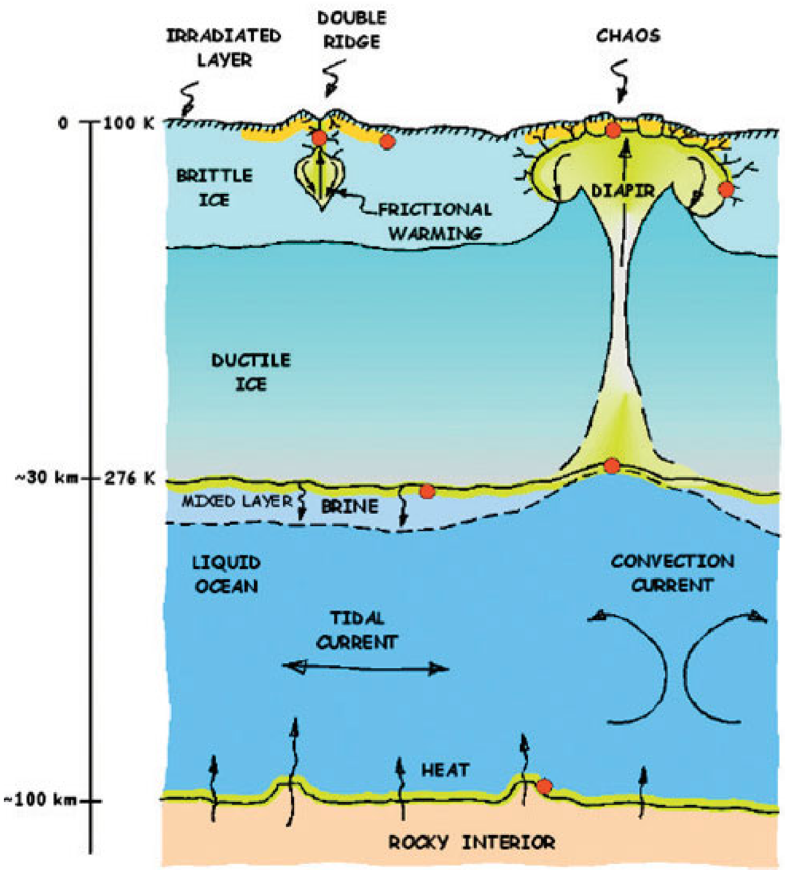

***Figure 1.** Diagram of a possible cross section of the outer zone of Europa, estimated to range from 80-150 km.*

In this model, it is envisioned that ductile ice lies underneath the brittle icy crust, and a liquid ocean above the rocky interior.

Processes such as warm ice diapirs that can upwarp the icy crust could provide exchange pathways between icy crust and ocean.

Possible habitable zones and location of putative biosignatures are indicated by green or yellow, respectively.

Figure from Figure 1 in Figureido et al. 2003.

NASA's spacecraft Galileo, which arrived in the Jupiter system in 1995, delivered magnetometer data that indicated there is a global ocean underneath the icy crust (Figure 1). While still unclear if this ocean is partly in the form of ductile ice or entirely liquid, the presence of liquid water, one of the main prerequisites of life as we know it, had astrobiologists up in arms. It was the first indication of the current presence of a large body of liquid water (about twice in volume of our ocean) in the solar system.

This insight led to various attempts during the subsequent decades to plan another mission to Jupiter, and I joined one of the science definition teams (SDT) charged with planning a space mission that would shed light on some of the mysteries of the Europan ocean. The Jupiter Icy Moon Orbiter (JIMO, Figure 2) SDT led by Ron Greeley, brought together planetary geologists, geophysicists, space engineers, and biologists. In the course of participating in the meetings, workshops, and conferences during the three-year work of the SDT, I learned to appreciate how much planning, engineering, and constant reality checks (called Technology Readiness Level, or TRL in NASA jargon) the planning of such a space mission requires. A mission of JIMO's magnitude had to have a nuclear reactor on board, supplying it with heretofore unprecedented energy and bandwidth for data transmission, and it would take decades and several billions of dollars to materialize. Science fiction type space ships as gleaned from *Star Trek* movies had never seemed more remote. JIMO's technology was ahead of its time with regard to feasibility (again, TRL), and besides publishing a scientific planning and advisory report on the mission, nothing became of this mission. But, I was hooked on Europa.

Coinciding with my work on the SDT, in April 2003 I participated in a field conference of the Europa Focus Group (EFG) in Barrow, Alaska, an Arctic beach town that remains frozen for most of the year. What does the Arctic have to do with Europa? In absence of a viable mission to Europa, and any hands-on possibility to sample the surface of this Jovian moon, its secrets will be locked beneath its rugged icy shell for the foreseeable future. The only remedy, at least on the time-scales of a scientific career and funding cycles, is a study of an Earth-analogue system, an environment on Earth that has characteristics of the remote environment of interest.

Thus more than ten years ago in Barrow, I found myself on a small two-propeller plane together with my colleagues of the EFG, and flew across the ice, a stomach churning ride in a plane that tilted from side to side to enable us to a clear view of the surface of the land-fast ice (Figure 3). This ice forms each fall, growing from the coastlines out into the open Arctic and eventually merging with the multiyear ice surrounding the North Pole. But it is not a solid surface, nor is it connected to the sea floor away from the actual beach. This landfast ice is just 1-2 m thick, and brittle. The ice breaks into floes that get shoveled around by the tidal currents and wind, creating rubble and compression ridges on the surface. These features seem remarkably similar to the pressure ridges, plate

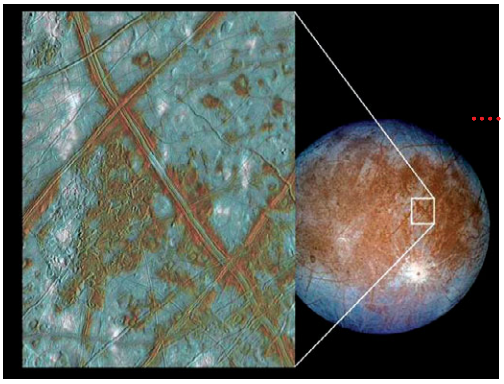

Figure 4. *False color image of Europa's crust obtained by NASA's Galileo Spacecraft between 1996-1997. The crust is made up of blocks which are thought to break apart and move against each other, resulting in ridges and fractures. Image Credit: NASA/JPL/University of Arizona*

Figure 3. *Ice floes on the Arctic Ocean observed during a flight with a two-propeller plane in April 2003.*

Figure 5. *Ice core retrieved from the sea ice, showing the brownish diatom layer at the intersection of ice and water. Cross section of the core is 12.5 cm.*

Figure 2. *Artist's conception of the Jupiter Icy Moon Spacecraft (JIMO), with Jupiter in the foreground and Europa in the background. Credit: NASA*

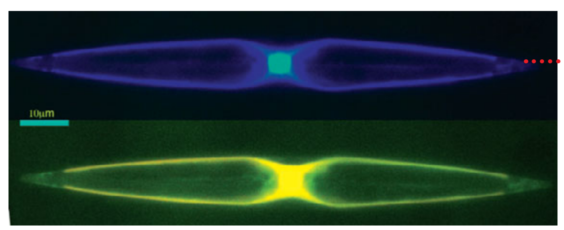

Figure 6. *Epifluorescence micrograph (above, blue light and below, UV excitation) of sea ice diatoms found in the lower 10 cm section of the ice.*

boundaries, visible on Europa's icy surface (Figure 4). Tidal flexing is much stronger on Europa though than on Earth, and recently, water plumes have been inferred from data stemming from the Hubble space telescope, pointing to water squeezed out periodically from sub-surface pockets under the variable tug of Jupiter's gravitational attraction (Roth et al. 2014).

These watery eruptions could be the source of the chaos terrain which is considered to have the highest astrobiological potential (Figureido et al. 2003, Figure 1), meaning that water or slushy ice containing potential life forms ('biosignatures') could be squeezed through conduits and cracks to the surface where they could be potentially sampled during a future mission to the surface of the moon.

My first trip to Barrow introduced me to the way the Arctic sea ice is investigated. Snow mobiles carry people as well as sampling equipment (usually on sleds pulled by the snow machines) several miles out onto the ice. Snow mobile rides over the rubbly ice are particularly exciting, and not without their share of angst when negotiating the ridges that never seemed that tall from the air. Nevertheless, these rides on the frozen ocean are necessary to reach sampling locations far from shore, where ice is cored to retrieve samples. In most cases, the lower portion of the ice (the one in contact with the underlying sea water) comes out brownish, revealing the color of sea ice algae that have overwintered in the brine channels of the sea ice. (Figure 5) When seawater freezes, pure water freezes first, leaving behind brine concentrated in channels transecting the ice. When sunlight returns to the Arctic in late winter/early spring, these algae find a favorable environment in those few centimeters above the ice-water intersection. Light, dimmed by snow and the overlying ice, and nutrient rich water, communicating through the lower brine channels, allow growth of the sea ice algae (Eddie et al. 2010). This algae layer is inhabited mainly by diatoms, unicellular, microscopic cells encased in a silica glass house, displaying remarkable adaptability in this cold, briny, and seemingly inhospitable environment (Figure 6). They convert light and carbon dioxide into carbohydrates as all photosynthetic organisms do, but more importantly, in this upside-down lawn they are the main food source for unicellular grazers or animals both in the ice as well as those in the surrounding ocean. I first viewed this habitat in awed amazement. While familiar with the literature, experiencing the vast expanse of this frozen ocean and its hidden life below, strikingly illustrated its role for the Arctic marine food web, from crustaceans to fish to sea lions to polar bears and whales and, of course, for the livelihood of the native Iñupiat subsistence hunters.

After my first exploration of this environment I wanted to dedicate more time to it, not only because of its importance as a earth-analogue system of Europa, but because of its role in the Arctic ecosystem. In collaboration with colleagues from the University of Washington and Columbia University, I was

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Author on a trip to the ice lead, the outer edge of the landfast ice, in May 2012. The open Arctic Ocean is in the background.

Polar bear, one of the Arctic macro fauna whose livelihood in spring is based on a food web fuelled by the sea ice algae as primary producers.

eventually able to obtain research funding from NSF's Office of Polar Programs, to study this sea ice community and its adaptation to life in the sea ice and its role in the food web of the Arctic Ocean.

Now looking back, I find it remarkable how my interest in an ocean on a faraway moon led me to study the Arctic sea ice ecosystem. A unique journey, first born of necessity but then opening a new window to research little anticipated when I first transitioned to this university in the desert. ■

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Susanne Neuer *is an Associate Professor of Biogeochemistry in the School of Life Sciences at Arizona State University. She received a Bachelor's degree in Biology from the University of Kiel, Germany, a MS in Oceanography from the University of Washington (as a Fulbright fellow) and a PhD from the College of Ocean and Atmospheric Sciences at Oregon State University. She completed postdoctoral training in marine biogeosciences at the University of Bremen in Germany before coming to ASU. She is a Co-PI of the NASA Astrobiology Institute at ASU. At ASU she has been teaching Oceanography, Ecology, Environmental Life Sciences and Marine Biology; she has also helped the development of the interdisciplinary graduate program "Environmental Life Sciences" which she chaired from 2009-2013. She is active in the Association for Women in Science (AWIS) and is a past councilor of its national board, and is currently serving as president–elect of ASU's Faculty Women Association. In 2009 she was awarded the Outstanding Achievement Award by the ASU Commission on the Status of Women, was named Senior Sustainability Scientist in 2010, has been nominated for several other awards at ASU, and has twice been named a fellow of the Hanse Institute for Advanced Studies in Germany. She is a member of the Association for Limnology and Oceanography, the American Geophysical Union, the Association for the Advancement of Science and has been a member of TOS since its inception.*
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