The Ocean's Seafloor – <u>One</u> Bio-Geo-System

Background, Situation

Modern systematic scientific ocean research started about 140 years ago. For the seafloor components, overwhelmingly rich and diverse observations soon led to separate specializations to the living biology or the inanimate geology. This separation persists today, despite the ongoing interest to join the two fields. That is because of their differences in data types, the complexity (diversity) of life forms, and conceptual difficulties such as the effect of organism behaviours on the physical seafloor.

Not only are these issues scientifically important, but they are important for the future society and ocean environment. Hence our application to VWS to support a symposium to integrate biology and geology of the seafloor.

The need for knowledge about the seafloor has increased dramatically as societal needs have expanded into our sea areas. Amongst other things, the past decade has seen significant activity in harvesting marine wind and wave energy, in locating and remediating underwater sites contaminated with unexploded ordinance (UXO), and in developing sites for aquaculture. In the near future, personal subs, tourism, more marine construction, and changes in fisheries will also demand attention. Whether building a platform for a wind turbine, or conducting a search for buried munitions, or managing fish resources, intimate knowledge of seabed characteristics is essential.

For these applications, when data are not immediately available, there is a desire to have models to fill gaps in seafloor information. And in the ocean a shortage of actual data is quite common. Prediction models of seafloor properties and of processes in geosciences have certainly advanced to provide reasonably good realizations of the seafloor. *However*, they often fail to provide reliable data for applications requiring more exact information. Mismatch between models and data is generally due to incorrect assumptions or incomplete parameterizations. For the seabed, evidence suggests that the mismatch between predictions and ground truth often correlates with high biological presence. In such cases, at best, a locally valid correlation is possible. A better solution would be to include the impact of biology when generating computed seabed representations through coupled biological and geological process modeling.

To improve prediction capabilities, the logical next step is the inclusion of biological effects on the physics of seafloor sediments and in models of seafloor processes. This coupling between biological and physical processes that interact to form local seabed properties and structures is currently almost non-existent. To date, the academic fields of benthic biology and geoscience have progressed sufficiently along parallel tracks without any catalyst to interact as there has not been a compelling enough reason for this coupling to occur. The specific issues that need to be resolved are: better compatibilities in data, model descriptions of growth and behavior, better descriptions of organism physical traits, role of population abundance changes, clearer thinking about sediment-biota interactions.

Developments in the Offering

Part of the challenge of this issue, and an impediment to progress, is the sheer amount of science that has been done in each separate field. It would not be possible for one proponent to cover all aspects. Thus, an important purpose of this proposed meeting is to harness the understanding of a *wide* set of experts. Here we can only mention some developments.

We first consider the example of data compatibilities, which is a bioinformatics issue of computing technology. The terms in the bio-databases cannot be used directly as input in existing models of seafloor physics, but have to be changed to numeric values for attributes like shell size and shape, feeding rate, growth pattern. The "Words-to-Numbers" challenge between descriptive and quantitative information types is only recently starting to be addressed using

diverse methods such as fuzzy set theory for traits, machine learning methods, and simulations as opposed to modelling – for instance with Lindenmayer systems for growths or agent models for behaviour. To meet the challenge substantial vocabularies will be needed, which can leverage important recent progress in digital taxonomy, for instance “Traitbank” in the web-based” Encyclopedia of Life”.

Solving the words-to-numbers challenge is only a first step towards a better modelling of seafloor properties. Biological processes impact the seabed in many ways: seagrasses and fields of tubeworms can act to trap material and reduce sediment transport; organisms often live within the sediments and create burrows that impact the bulk properties of the sediment; and organisms feeding or inhabiting the seafloor can change the local roughness characteristics of the seafloor. The organisms’ mass itself, and aspects like produced gas and hard structures (e.g., shells, exoskeletons), need to be included in our understanding and quantification of the seafloor physics, especially where high-frequency sonar imaging is used.

Biological processes can change substantially on scales of hours, days, years, and decades. Time variability in biology is higher and more complex than what is encountered in geosciences. In addition, sudden episodic events may influence a biological system. Interactions between organisms and their environment drive population and community level changes. For this, ecological interactions, especially at the population level, need to be interfaced with the uncertainty bounds on predictions of the physical state of the seafloor.

Another aspect should be mentioned, which will fascinate the meeting and confront us in achieving practical solutions to combine the bio and geo. The high diversity and variability of species living on and in the seafloor is a severe challenge in modelling and characterization of the impacts of these species. Pragmatic solutions exist including functional groups, dominant species, and ”representing organism” (for a phenomenon). To decide whether or not a species is considered in modeling, its impact must be known. It is proposed to determine the critical abundance below which the species does not affect physical methods or processes as well as the relative impact of different species to determine which species within a community have the greatest impact. The meeting will be an important step in determining the most effective way to proceed.

Only a small amount of progress with respect to the topics outlined above, in relation to joining the bio and geo, has been seen for decades. Facing these difficulties, quick and simple solutions are not expected. However we seek a ***practical*** approach in mapping and predicting seafloors, and that will assist. Also, we will provoke thought on unconventional methods and technologies which will offer more rapid progress.

Other formal support gathered. The issues raised here are becoming more important. The Symposium is timed at an early stage in developments and will contribute strongly.

As an example of developments, recently NATO endorsed formation of a Specialist Team (ST) comprised scientists and subject matter experts to discuss cases requiring more understanding of the intersection of bio and geo factors at the seabed. The ST will also bring together and support discussions amongst scientists in biology, geophysics, acoustics, and related disciplines - academic and laboratory scientists. It will summarize results from the discussions and recommendations in a final report to NATO which will then encourage research in this important area. It is clearly stated that all the study is seen as initiation of new fields in research that need to be transitioned to academic institutes after the report, and NATO’s engagement ends at that point.

The importance of this governmental program since 2014 is that it sparked innovation in the bio-geo problem. At every meeting there were high-levels of interest and energy in exploring these topics resulting in some very important recommendations for future studies and approaches to gain more scientific understanding of the bio-geo intersection. Also potentially, ship and lab time will be available to test outcomes – always important in science.

Focus the Problem.

The debates on combining bio-geo so far have reached the consensus that it would be best to focus on some practical issues, to reduce the size of the overall problem and offer 'testbeds' for concepts. The practical direction also will encourage economy in the thinking and offers ways to validate outputs using actual data from field systems.

Four *foci* are identified as high-priority and needing immediate improvement by consideration of biological influences on seafloor physics:

(i) High frequency seafloor imaging. Using sound transmissions of kilohertz and even megahertz range, the seafloor is imaged very closely for many different reasons: habitat delineation, object discovery, evidence of mobility, measuring consolidation, etc. At those (high) frequencies individual objects such as shells affect the results, in what is called reverberation, which can help or hinder the survey results. The many types (and adjustments) of the sonars doing this work have led to a patchwork of often conflicting results even over the same ground at different times. To a large extent biological factors seem to be at play.

(ii) Sediment transport. Erosion, transport and deposition are important factors in practical issues like fate of contaminants and rubbish, hiding (and then uncovering) dangerous objects, stability of infrastructure like pipelines. Biology is known to interfere with the transport, for instance increasing deposition by trapping sediment in baffles of weed, reducing erosion with biofilms.

(iii) Geo-mechanical properties. The load-bearing strengths - the geomechanics - of seabeds are very important for underwater infrastructure such as pipelines and settlement of objects out of sight. The biological concerns here are principally presence of strengthening shelly fabrics and oppositely, creation of weakening voids by burrowers.

(iv) Underwater vision and access. This rather new and underdeveloped field is largely driven by new technologies of autonomous underwater vehicle (AUV) video, laser scanning and image processing. Obviously, epibenthic weed, including rafted weed, is a hindrance, but so is biofouling. For operation of the new modules, being able to predict when conditions are best is a great help.

From this list we can see that the four very practical issues will focus the problem onto just a number of geometries, phenomena, organism types, and settings. That is helpful to the symposium, and also offers more rapid benefits to society and the ocean ecology.

Next steps/ requirements.

Intensive review of methods and concepts by geoscientists and biologists are mandatory as the first step to achieve progress in these four foci, and thereby in the general subject. A reciprocal and crossing understanding among the two disciplines needs to occur.

Small expert groups need to develop and present an integrated understanding of the specific foci and how biological phenomena contribute to or alter the physics. The second step is the development of a descriptive bio-geo model that is represented by a schema and also in mathematics. Each step will involve *both* the geo and bio. The ultimate goal is to develop computational models including complex issues like population variability, diversity, physical parameters, transports and movements of materials, and environmental conditions to predict seafloor geotechnical and acoustic properties. Finally, new strategies need to be developed to transfer results of physical modelling into information that is directly useful in making better estimates and predictions of the state of the seafloor.

These strategies sound like they involve much work. True. That is why we concentrate on the theme of focus, innovation and clarity of concepts from best experts. And by adopting a modelling approach (as opposed to say, a "database" approach), modules represent concepts,

can be replaced as improvement proceeds, and are themselves the detailed due-diligence documentation of the predictions that are made for practical use.

In the task we are greatly assisted by the recent growth in large, ocean-wide data resources. Here is a short list: (a) “Encyclopedia of Life” and other systems which detail the traits of organisms. And iOBIS which is a huge catalogue of organism occurrences. (b) “dbSEABED”, an integration of all the sediment/rock/biologic substrates worldwide, now supplying mappings and detailed information for fishery-management, object detection, pure research, etc. (c) “Wavewatch III” and “OTIS regional Tidal Solutions”, giving information on wave and tide dynamics that affect marine shallow marine ecologies so strongly. (d) “World Ocean Atlas” giving essential temperature, salinity and nutrient values to delineate - along with dispersal considerations - the habitat extents of organisms.

The proposed conference will concentrate on the bioinformatics technologies that will allow people to efficiently tap into these data resources.

The role of innovation is crucial. Hence the need to gather a lively group, with a good demographic, much experience and – as we can tell from enrolments, enthusiasm. Partly the innovation is a matter of getting clarity in concepts. For instance, for bioturbation what exactly determines whether sediments are loosened or tightened by a burrower – a vexed topic that we hope to resolve in the meeting so that effects can be coded in models. But innovation it is also a matter of bringing in new math and computing techniques such as automated information extraction, fuzzy set theory, supporting databases, the newest turbulence and sediment transport modellings, clever ways of dealing with biologic diversity, etc.

The Planned Symposium Structure

Aims. Briefly, the goal of the symposium is to initiate a new form of interdisciplinary cooperation in seafloor sciences. The intention by assembling biologists and geoscientists together is to generate awareness of the other discipline and to understand how biology and geoscience interact. Exchanges between scientists of different disciplines discussing their difficulties and possible solutions will force them to explain their thoughts in basic terms, avoiding discipline jargon. This strategy has proven very helpful in earlier ST discussions, and has attracted tremendous positive response in the lead-up to this proposal. It is the best hope for getting a combined bio and geo picture of the seafloor.

In order to develop a sustainable new scientific direction, the meeting has the explicit objectives: (i) to outline and define the scientific challenges, (ii) seek innovation and clarity of ideas, and (iii) to initiate cooperation and joint bio-geo projects.

Concept of the Symposium. The central idea of the intended symposium is intense discussion over 3 days of the seafloor as one bio-geo-system.

The key to achieve this goal is the exchange and mutual learning between the involved disciplines. We want to have both, the well-organized information and direction of general sessions, plus the innovation from small groups. We have taken great care to invite scientists whom we know are top experts, keen, and good at collaborating. This is important. It is also important that there is a balance in ages, genders and nationalities, promising a lively meeting. That blend also brings up-to-date, worldwide awareness of the newest technologies in data, modelling, and the two sciences. All expert groups will consist of experienced senior and young scientists.

We anticipate a lot of provocative questions, but it is important that people are there too who can offer answers. We want to trigger a new unusual way of looking at “established” concepts and their validity. It can be a way to break walls and open eyes for new ideas.

Organization of Time. The agenda is very active, and adopts some rather new formats to achieve that - for example, small ignite talks instead of introductions.

a) Participants prepare beforehand with one or more abstracts and/or images in the proceedings. Their affiliations, interests are dealt with there, not in introductions.
b) In place of introductions, we will have brief, hopefully provocative "*Ignite Talks*" of a few minutes per invitee, in the first day.
c) Speakers will speak standing, with wireless microphone in the room. We will need a floor assistant. There will be about 50 participants, so the pace will be fast. We foresee that the venue will be the same as the accommodation. Provide internet connectivity for on-the-fly document editing.
d) Scattered through the symposium, some expert "Keynote Talks" for the outline of challenges and to educate the meeting on the most important concepts.
e) Small "Expert Groups" of mingled biologists and geoscientists, and concentrating on one of the four practical foci. They are to improve the geoscientists' awareness for biology, and *vice versa*. The groups will be presented with definite tasks in each session, and a rapporteur system will be used to harvest the results.
f) They will make short reports for each session, and then lead "General Discussions" on their view and output on the task,
g) The symposium will publish a volume, consisting of the participants' abstracts, the talk abstracts, and discussion abstracts. It is planned to make this citeable, hopefully through VW-S.

An expected by-product of the symposium is the initiation and ideally, outlining of fresh joint research projects (biology, geosciences, physics), funding, then community software and publications. By community software, we refer to facilities like the CSDMS at Colorado, which houses and serves open-source, documented, integrated model codes.

Meeting composition. In total eight participants (~20%) qualify as young scientist. Their role at the meeting will be relevant as they will be encouraged to question established routines and propose alternatives. In addition, their familiarity with new technologies may offer an unexpected input. For their role after the symposium we expect that they leave with an enthusiasm for the intended change that may help to accelerate the establishment of the new treatment of the seafloor as one bio-geo-system. In the long run, they are hopefully the persons who will carry the work we kick off with the symposium into the next generation of researchers.

Among the confirmed participants at this stage 35% women, which figure will probably rise as more younger scientists enroll. Gender balance is important to us for range of views and equal opportunity.

Conclusion

Although the explanation above is rather technical, the work has strong societal dimensions. Society cares about the oceans and depends on them for food, recreation, utilities and climate. Better understanding of the inanimate and living parts, and better mapping, leads directly to evidence-based management decisions for ocean areas, such as Marine Protected Areas. There is a lot to do to clean up our marine seabeds and this project keys directly into that goal. These societal factors have helped with the enthusiastic response already for the Symposium from top experts, young scientists, and practitioners.

Further Reading

INSTAAR 2015. *dbSEABED: Information Integration System for Marine Substrates*. [„http://instaar.colorado.edu/~jenkinsc/dbseabed/"]

Levinton, J.S. 2013. *Marine Biology: Function, Biodiversity, Ecology*. (4th Edition). Oxford Univ. Press, 576p.

Seibold, E. and Berger, W.H. 2013. *The Sea Floor: An Introduction to Marine Geology*. Springer Science & Business Media, 358 p.

Smithsonian Institution 2015. *EoL: Encyclopedia of Life*. ["http://eol.org"]