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Program options to explore ocean worlds

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ABSTRACT

Including Earth, roughly a dozen water ocean worlds exist in the solar system: the relict worlds Ceres and Mars, vast oceans inside most of the large Jovian and Saturnian icy moons, and Kuiper Belt Objects like Triton, Charon, and Pluto whose geologies are dominated by water and ammonia. Key pieces of the ocean-world science puzzle – which when completed may reveal whether life is widespread in the cosmos, why it exists where it does, and how it originates – are distributed among them. The eventual exploration of all these worlds will yield humanity's total tangible knowledge about life in the universe, essentially forever. Thus, their exploration has existential significance for humanity's self-regard, and indeed perhaps of our place in the natural scheme. The matter of planning how to pursue such a difficult and unprecedented exploration opportunity is therefore historic. The technical challenges are formidable, far harder than at Mars: missions to the Jovian and Saturnian ocean worlds are severely power-limited; trip times can be as much as a half decade and decade, respectively. And the science targets are global-scale oceans beneath kilometers of cryogenic ice. Reaching and exploring them would be a multi-generational undertaking, so again it is essential to plan and prepare. Today, we lack the instrumentation, subsystems, and remote operational-intelligence technologies needed to build and use exploration avatars as good as what we can envision needing.

Each ocean world holds a piece of the puzzle, but the three priority targets are Europa at Jupiter, and Enceladus and Titan at Saturn. As with the systematic exploration of Mars, exploring these diverse worlds poses a complex technical and programmatic challenge – a strategic challenge – that needs to be designed and managed if each generation is to see its work bear fruit, and if the space science community is to make most effective use of the public money devoted to the quest. Strategic programs benefit from coherence. In only 15 years, the Mars Exploration Program (MEP) has transformed humanity's view of Mars as a once and future habitable place, a world quite possibly holding relict evidence of life. Finding such evidence, we would study it to know if that life shared an origin common with Earth life. However, life in the ocean worlds could not have shared our origin, so exploring them opens another level in our quest to understand life in the universe: not only to places with vast salt-water seas known to contain organics and hydrothermal seafloors active today, but to places where anything alive cannot be related to us.

MEP's success – from its presence in the public consciousness to its rewriting of planetary habitability – make it an obvious template and source of lessons learned for a viable ocean worlds exploration program (OWEP). Six attributes of the MEP are analyzed for application to a potential OWEP. From this, five hypothetical programmatic scenarios are compared to the default case, and conclusions drawn. A coherent OWEP should have several parts: first, dedicated continuous investment in enabling technologies; and second, two directed-purpose, medium-class (~$1 B) missions per decade that conduct pivotal investigations on a documented roadmap. Science could start in 2035, informing development of decadal flagship missions after Europa Clipper, to the places revealed to hold the most promise. The fastest pace of scientific discoveries would require access to high-performance propulsion infrastructure, e.g., the Space Launch System, Falcon Heavy, and high-power in-space solar electric propulsion, all capable of halving trip time. Not including these boosts, such a program would cost about a half-billion dollars more per year than NASA's existing mission portfolio; the program architecture funded today cannot deliver a strategic OWEP while also sustaining balance among other solar system exploration priorities and opportunities.

Follow the Water. Yes, into the Ocean Worlds.

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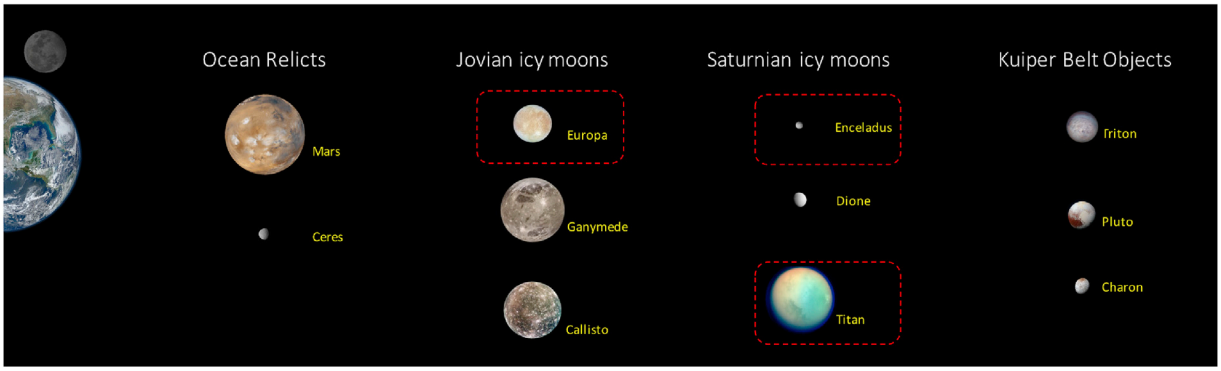

Fig. 1. About a dozen ocean worlds exist in the solar system, with diverse environmental conditions and states. They are the only planetary destinations available for humanity to learn the limits of life in tangible detail. Three have special priority, for diverse reasons.

1. Introduction

Today we know of at least ten Ocean Worlds in our solar system, including Earth of course but otherwise a quite diverse set. To learn the limits of life in these places – the potentially habitable worlds nearby – we have to explore them all.

This will take many decades to do. Having a clear strategy is essential if we are to prioritize among the feasible options, and make the smartest investments.

Reference [1] discusses how to scientifically identify, confirm, and study worlds that may have, or may have had, oceans. Reference [2] surveys the phenomenology of ocean worlds throughout the solar system. Fig. 1 shows an ocean-world taxonomy and highlights the 'ocean-world starter set' among them: the three most likely to reveal the most, soonest, about the extent and diversity of life in our solar system.

2. Europa

Europa, second-highest flagship mission priority of this decade [3] and the target of NASA's planned Europa Clipper, ought to be habitable (Fig. 2). Almost as big as Earth's Moon, it has an internal ocean with twice as much water as all of Earth's seas, and likely a hydrothermal seafloor (Fig. 3). The ice crust enclosing the ocean, of indeterminate thickness, is nonetheless geologically young, with ample evidence of dramatic tectonics that imply opportunities for exchange between ocean and surface over geologic time (Fig. 4). The surface is irradiated by Jupiter, likely generating oxidants that get cycled into the ocean over geologic timescales.

Europa is our solar system's intrinsically most promising home for an alien ecology unrelated to Earth life. The next step of exploration would be a comprehensive investigation of the moon's habitability, which is indeed the purpose of Europa Clipper. Subsequent steps could include: 1) landing at a confirmed ocean-surface exchange zone, to access ocean material deposited near and on the surface; 2) local mobility in such a

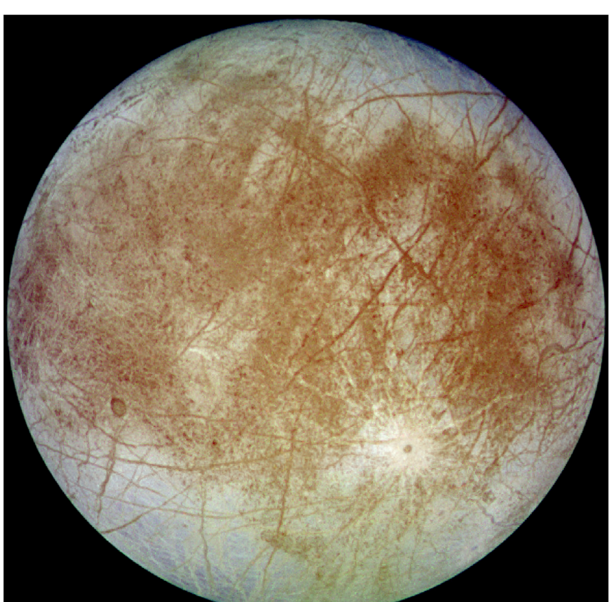

Fig. 2. Europa has one of the youngest surfaces in the solar system, an ice shell enclosing a salt-water ocean about twice as large as Earth's.

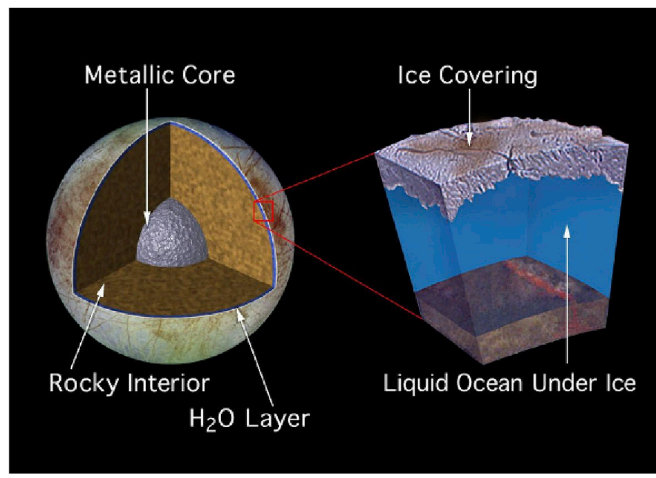

Fig. 3. The floor of Europa's ocean is silicate rock, and hydrothermal activity is likely.

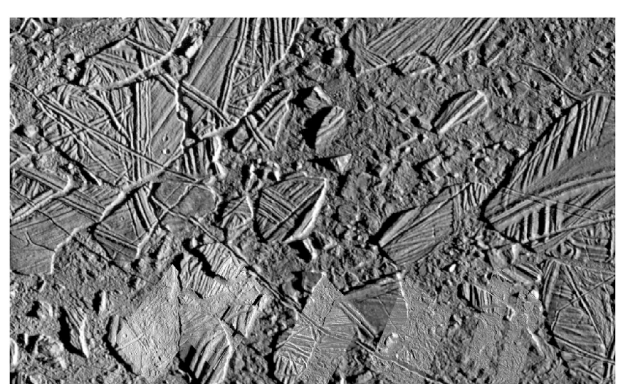

Fig. 4. Significant exchange between Europan ocean and surface is strongly implied by chaos morphology. Image: NASA/JPL/Univ AZ.