The Throat of Kraken : Tidal Dissipation and Mixing Timescales in Titan's Largest Sea

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Introduction: Of Titan's three seas, Kraken has the largest area, and sprawls over the widest range of latitude and longitude. This extent means it sees the largest variations in tidal accelerations due to Saturn's gravity, and thus has the largest tides. New Cassini observations map the seas (figure 1) and allow quantification of tidal processes : a feature of particular interest is a narrow 'throat' (figure 2) between the two main basins of Kraken. These basins are large enough to serve, like Ligeia Mare, as splashdown sites for future missions like the proposed Titan Mare Explorer (TiME). This throat may see strong tidal currents and significant energy dissipation, as well as acting to restrict mixing of the sea composition.

Tidal dissipation in oceans was a central topic in pre-Cassini Titan science [1,2], since such dissipation would be expected to circularize Titan's eccentric orbit unless the oceans were deep, or confined to small basins [3,4]. Although dissipation in Titan's interior [5] also presents the same issue, it is interesting to re-examine the question of dissipation in the sea.

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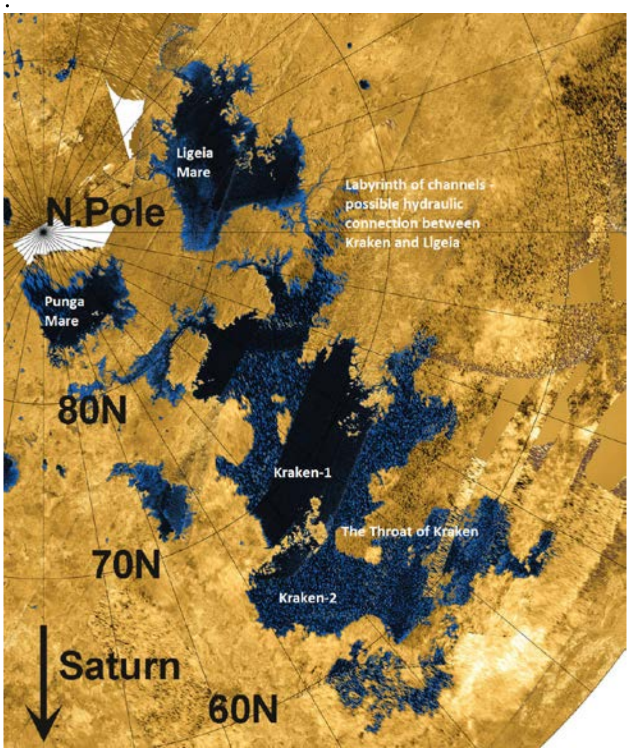

Figure 1. Cassini RADAR mosaic, showing the Titan seas Ligeia, Punga and Kraken. The latter has two main basins, separated by a narrow throat. The 10^{o} latitude circles are ~450km apart.

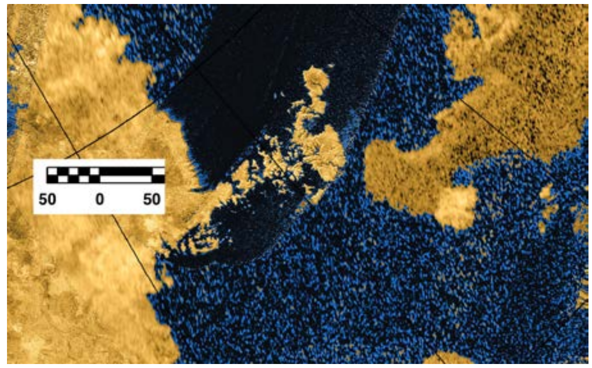

Figure 2. A zoom of the 'throat' that constricts communication between the two main basins of Kraken. The main strait is 17km wide and about 40km long.

The Throat of Kraken : The main part of the throat is rather comparable in dimensions with the Straits of Gibraltar (13km wide, ~40km long). However, in terms of the juxtaposition of a main channel with an adjacent labyrinth of small islands and channels, the Aland islands separating the Gulf of Bothnia from the Baltic are perhaps more similar geomorphologically.

Tides : The changing distance to Saturn, and its libration of ~3^{o} in longitude, due Titan's eccentric orbit, leads to a changing tidal potential. The equipotential ellipsoid (i.e the response of a global ocean) on a rigid Titan would vary by some 10m. Within the narrower extent of Kraken, Tokano [6] using a low-resolution numerical tide model found a tidal amplitude of ~4m, and noted that a possible constriction between two basins (not accurately resolved in Cassini data at the time) may be important.

In fact, the tidal amplitude may be reduced by a factor of several due to the response of Titan's flexible crust [5,7] underneath the sea. Nonetheless, a tidal amplitude of the order of 1m can be expected.

Considering the basins crudely as ~300km across (~70,000km area), a tidal variation of 1m corresponds to some 70km^3 of liquid moving from one basin to another. In a strait 17km wide and (say) 20m deep, this corresponds (in a quarter of a Titan day, ~400,000s) to tidal currents of some ~0.5m/s, a remarkable speed for Titan, dissipating ~1GW of mechanical energy. By itself this is too small to meaningfully affect Titan's orbit (for which ~100GW would yield a ~1Gyr e-folding eccentricity decay time [5]), but underscores that shallow seas (and in even the recent past the sea configuration may have been very different from present) could have significant tidal dissipation.

Tidal currents in narrow straits can lead to striking dynamic topography such as whirlpools (which conceivably could be detected with Cassini remote sensing). The Corryvreckan off the coast of Scotland has a tidal maelstrom which generates a roar that can be heard 16km away - future Titan exploration might consider acoustic detection of such turbulence both through the air and through the sea (floating capsules would likely be equipped with sonar in any case [8])

Mixing Timescales : The concentration of Titan's seas at high northern latitudes attests to a climate control of the distribution of liquids, with the north presently favored for accumulation of methane rainfall because in the present astronomical epoch [9], the rainy season is longer in the north. A variation with latitude of precipitation, as well as of evaporation, might lead to a gradient in liquid composition if the seas are not well-mixed by tides and wind-driven currents. The latter have not yet been modeled, but mixing by tides can be estimated.

Given a tidal cycling of 70km^3 of liquid each Titan day through the throat, and a volume of ~30,000km^3 [10] for each basin, a first-order mixing timescale is ~500 Titan days, or ~25 Earth years.

Since this timescale is long compared with a Titan season, if the supply of methane-rich rainfall to the seas varies with latitude, we might expect there to be (at some seasons at least) a compositional difference between the two basins, unless wind-driven circulations somehow augment mixing through the throat (which seems unlikely). The magnitude of such compositional differences will need to be evaluated with numerical models, preferably taking possible stratification [11] into account. On the other hand, the mixing timescale is short compared with the period of astronomical variation of the seasons (the Croll-Milankovich cycles) of ~50,000 years so long-term geological consequences of the sea composition (notably, the composition of evaporites left after the seas evaporate) should be somewhat uniform with latitude.

Future Work : Now that the seas of Titan have been mapped more or less completely, and bathymetry estimates are emerging, the stage is set for numerical simulation of ocean processes on this remarkable world. Tides at Ligeia are small (it is smaller in extent, and rather far from the region of peak tides) but mapping suggests a possible hydraulic connection between Ligeia and Kraken - a less effective one than the Kraken throat - which will also be interesting to examine in a tides and mixing context.

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