A POSSIBLE INTERIOR LAYOUT OF (16) PSYCHE COMPATIBLE WITH THE RADAR OBSERVATION. Y. Kim[1] and M. Hirabayashi[1], [1]Auburn University, Department of Aerospace Engineering, Auburn, AL 36849 (yzk0056@auburn.edu).

Summary: We introduce a numerical approach using a layered structure modeling and FEM to investigate the internal layout distribution of Psyche, which is assumed to be a differentiated body. This work will identify possible structural conditions compatible with the observed features.

Introduction: In 2022, NASA will send a spacecraft to explore (16) Psyche, the largest M-type asteroid in the main belt [1-2]. This asteroid likely contains abundant metals on the surface inferred by its high radar albedo (~0.34) [3]. Although it is still not clear how this object has been formed to have the current appearance, some possible stories exist.

One of the working hypotheses is that Psyche could be a differentiated body that experienced potential processes (i.e., impact and ferrovolcanism) to reveal the metallic materials in the core onto the surface [4-5]. This partial metal surface with the silicates can be supported by Psyche's measured bulk density (~4.0 g cm^{-3}) and radar albedo variations. Using the data currently available for Psyche, we developed a new numerical approach to investigate the compatible interior layout with the observed quantities and features. We modeled Psyche's structure as layered and defined the size of layers by applying the Finite Element Model (FEM) technique. With knowledge acquired in the upcoming Psyche mission, this work will help better understand the internal structure of Psyche.

Numerical Approach: We set an inverse problem to constrain the size of the interior layout compatible with the observed quantities derived by remote sensing data and assumed parameters as schematized in Figure 1. To solve this problem, we introduce the layered structure model and the FEM that provides the pressure distribution of the layered structure.

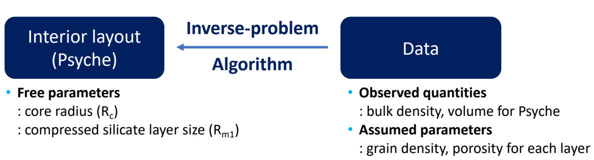

Figure 1. Inverse problem schematic to constrain the interior layout of differentiated Psyche

Layered structure modelling. If the metallic core covered with the silicate layer is the case for Psyche, the silicate layer is likely to be compressed under the high-pressure regime as observed in the lunar crust [6]. Many earlier studies [7-10] showed that, in the case of silicate soil, the compaction begins when the applied pressure exceeds ~10 MPa. Especially for Psyche, the first few sub kilometers from the surface reach this crushing limit, allowing the subsurface to hold lower porosity than the top surface layer. Although compaction would not occur as significantly as seen in the lunar crust, we still expect that less-scaled compaction would be available under the pressure regime (~15 MPa) in the silicate layer of Psyche. Considering this mechanism, we model the structure as three layers that consist of a metallic core, compressed, and un-compressed silicate layer, as seen in Figure 2. Each layer has a different bulk density set as a combination of grain density and porosity. The grain density of the silicate-rich and iron-rich layers are determined as the bulk density of stony meteorites (3 g cm^{-3}) and iron meteorites (7.5 g cm^{-3}), respectively [11]. Unlike the grain density, porosity is still an uncertain parameter to be determined. We thus use a wide range of porosity for each layer to avoid any biased structural condition depending on this parameter. The core porosity ranges from 0–30%, while the top surface ranges 10–50%. The porosity of the compressed layer is defined as 30% reduced values from the top surface layer based on the one-dimensional compression tests of a silica [9-10].

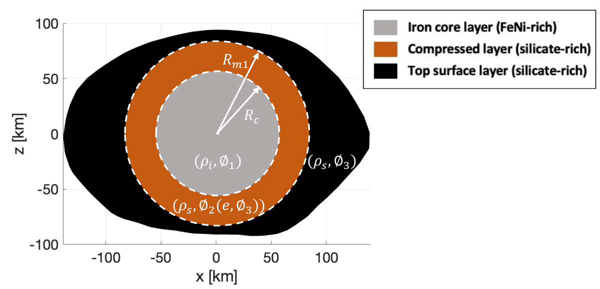

Figure 2. Three-layer model layout that consists of a metallic core, compressed silicate layer, and top surface layer (un-compressed)

FEM approach. The FEM is developed to calculate the stress distribution when the object rotates uniformly. The stress calculation is based on the linear-elastic deformation. For the boundary condition, we apply three constraints for translation motion. We then apply an iterative conjugate gradient algorithm for the least-squares method into the inverse matrix calculation to mitigate singularity issues [12].

In the simulation, Psyche is set to rotate along its shortest principal axis with a constant spin period of 4.2 h [3]. We use Gmsh – an open-source 3D finite element mesh generator – to create a 4-node FEM mesh from the latest radar-derived surface mesh [3]. The final mesh has 3,344 nodes and 15,569 elements. For all the simulations, the total bulk density is fixed at 4.0 g cm^{-3} [1]. The geophysical parameters, Poisson's ratio and Young's modulus are set to be 0.25 and 10^7 Pa, while we note that the stress field is independent of Young's modulus in the linear-elastic deformation [13].

Inverse-problem algorithm. We implemented the inverse-problem algorithm to constrain the size of the interior layout given the observed quantities and assumed parameters described above. The algorithm includes the following steps. We first randomly define the initial layout in the three-layer model and apply it to the FEM to compute the pressure distribution of the entire structure. We then find the boundary layer that reaches the crushing limit of silicates (~10 MPa) using the pressure data. This boundary layer indicates where the silicate layer indeed starts to be compressed and must be consistent with the compressed layer from the initial layout. Suppose the boundary layer does not match the compressed layer from the initial layout. In that case, we redefine the structure layout and iterate the process above until the matched case is found. Then the simulation con-verges into and outputs the final interior layout.

Interior structure layout: Figure 3 shows a color map representing the constrained core radius within the assumed porosity ranges. We confirmed that the core becomes larger as the core and silicate layer have higher porosities. Within the assumed porosity ranges, the core radius varies from 72 to 88.5 km, which takes up 30 – 45% of the overall size of the Psyche. This core size leads the silicate layer to be formed up to 16 km thick (low-er limit) and 68 km thick (upper limit). Since we assumed the spherical core shape as shown in Figure 2, the current shape has the lower and upper limit along the shortest and longest axis, respectively.

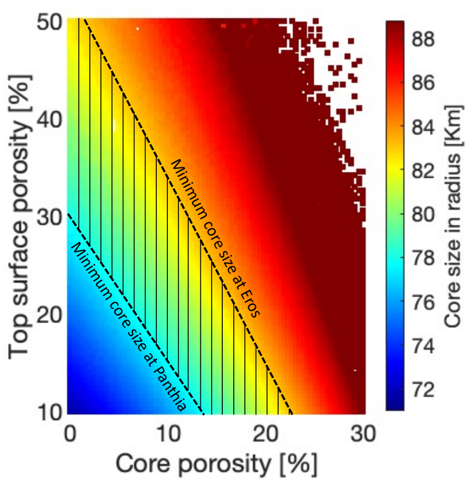

Figure 3. A colormap shows the constrained core size with the assumed porosity ranges. The hatched area represents the possible core size to be exposed at Panthia.

Core size compatible with the observed features. The latest shape model exhibits almost certain two craters on Psyche's surface [3]. One named Panthia is located in the northern mid-latitudes with a crater size of 90 km. The other, Eros, has a smaller size of ~63 km in the southern hemisphere. Unlike Eros, Panthia is detected to be optically much brighter than the surroundings, which indicates the metal concentration in this region. We note the impact cratering as a potential mechanism to expose metal at the crater-like region [4]. If a transient crater formation penetrates the upper silicate layer to reach the core during the excavation stage, the ejected materials can be made up of mixed silicate and metal and eventually falls onto the neighboring area that can explain the localized metal concentration. Given the final crater sizes, we investigated the maximum excavation depth at Panthia and Eros and found the compatible core size to reach the metallic core. If the metal concentration truly exists at Panthia but not at Eros via the impact cratering, the core radius should be between 78–83 km, which takes up 34–40 % of Psyche.

Compatibility with ferrovolcanism scenario. Ferrovolcanism denominates the process that the core materials intrude into the covered rocky layer or even erupt onto the surface of planetesimals while solidifying. A recent study revealed that the differentiated body with a silicate layer less than 50 km thick is more likely to experience the ferrovolcanic surface eruption when its core contains sulfur-rich FeNi melts [5]. The constrained structural layout from our simulations still supports the ferrovolcanism scenario because all cases have regions where a silicate layer is formed less than 50 km thick. If ferrovolcanic surface eruption truly existed, Psyche would have the sulfur-enriched surface. As a final note, we address that our results of the interior layout were defined using the current state data (i.e., shape, rotation period, and bulk density), which might be different at the period of ferrovolcanism.

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