HB-DA-VMM-01, Volumetric Mineralogy Mapping via Satellite Spectroscopic Data

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Abstract

This report derives the computational architecture for the **HB-DA-VMM-01** protocol, focusing on the conversion of 2D hyperspectral surface reflectance into 3D volumetric mineral density maps. By utilizing Multi-Angle Imaging SpectroRadiometer (MISR) data and Deep Bayesian Inversion, we resolve the subsurface distribution of rare-earth oxides and silicates. This model utilizes high-dimensional data processing to predict ore-grade continuity within the HB-09 to HB-12 extraction sectors, ensuring resource viability prior to physical excavation.

1 Radiative Transfer and Surface Reflectance

The mapping process begins with the retrieval of the surface BRDF (Bidirectional Reflectance Distribution Function). We model the radiance $L(\lambda)$ captured by the satellite sensor as a convolution of the atmospheric transmission and the ground reflectance ρ:

$$L(\lambda) = \tau_{\text{atm}}(\lambda) \cdot (1)$$

In the **HB-DA-VMM-01** framework, we apply a Non-Negative Matrix Factorization (NMF) to the hyperspectral cube $\mathbf{X} \in \mathbb{R}^{B \times N}$, where B is the number of spectral bands and N is the number of pixels, to isolate pure mineral endmembers.

2 Volumetric Inversion via Stochastic Tomography

The transition from surface mapping to volumetric mapping requires the solution of an ill-posed inverse problem. We define the subsurface mineral density $\phi(z)$ at depth z as a function of the surface signature intensity and the local gravitational gradient Δg.

2.1 The Kernel of Volumetric Diffusion

The relationship between surface spectral intensity S and subsurface volume V is governed by the Fredholm integral equation of the first kind:

$$S(x, y) = \int_0^D K(x, y, z)\phi(x, y, z)dz + \epsilon \tag{2}$$

where K is the sensitivity kernel (determined by the penetration depth of electromagnetic signatures) and ϵ is the sensor noise.

3 Advanced Spectral Data Processing

To manage the petabyte-scale datasets generated by the HB-Sat constellation, we utilize a manifold learning approach. This reduces the spectral dimensionality from B bands to a latent space $\mathcal{Z}$ of dimension $k \ll B$.

3.1 Table of Mapping Parameters

Variable	**Statistical Mean**	**Variance (σ^2)**
Spectral Resolution ($\Delta\lambda$)	2.4 nm	0.02
Volumetric Density Precision (ϕ^*)	0.942 kg/m^3	0.008
Inversion Correlation Time (τ)	18.5 s/pixel	1.4
Noise Floor (SNR)	420:1	12.0

Table 1: Operational Benchmarks for HB-DA-VMM-01 Mapping Simulation.

4 Resolution of Subsurface Anomalies

During the analysis of the HB-11 sector, the VMM protocol identified a "Spectral Shadowing" effect. This is modeled using a modified Langevin-type equation to account for the stochastic distribution of scattering particles in the regolith:

$$\frac{d\mathbf{p}}{dt} = -\nabla_{\mathbf{p}} U(\mathbf{p}) + \sqrt{2D}\boldsymbol{\zeta}(t) \tag{3}$$

where $U(\mathbf{p})$ is the potential energy of the mineral grain distribution and $\boldsymbol{\zeta}(t)$ is the Gaussian white noise representing geological entropy.

5 Conclusion

The **HB-DA-VMM-01** protocol successfully bridges the gap between orbital observation and subsurface mineralogy. By applying rigorous data analysis techniques to multi-angle spectroscopic data, we can visualize resource distributions with 94% accuracy down to a depth of 15 meters. This capability is essential for the strategic planning of the Heidenbillg extraction colonies.

Mathematical Appendix: Bayesian Density Estimation

The posterior probability of the mineral density distribution $P(\phi|S)$ is computed via the Evidence Approximation:

$$P(\phi|S) = \frac{P(S|\phi)P(\phi)}{\int P(S|\phi')P(\phi')d\phi'} \tag{4}$$

The most probable density ϕ_{MAP} corresponds to the global maximum of the high-dimensional objective function, which identifies the optimal drilling coordinates for the HB-12 sector.