Modelling of complex electromagnetic targets using advanced non-linear approximator techniques

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Summary

- O(N) numerical techniques
  - Rapid calculation times
  - Minimal memory requirements
  - Simulation of complex models
- Localized Nonlinear (LN) Approximation
  - Inductive modes
  - Multiple body problems
  - Magnetic effects, static and time-varying
  - Polyhedral primitives

Introduction and Background

- LN Approximator
  (Habashy, Groom and Spies, 1993)
  estimates only of the current channelling response for a spherical scatterer
- Magnetic fields derived from the internal electric currents (electric field formulations)
  inductive responses to be underestimated

- integral equation for EM scattering

$$E(r) = E_b(r) + \int dr' G(r, r') \cdot Q(r') E(r')$$

- Localized Nonlinear (LN) operator

$$E(r) = \Gamma(r, \omega) E_b(r)$$

- external field estimate

$$H(r) = H_b(r) + \frac{\nabla}{i\mu\omega} \times \int dr' G(r, r') \cdot Q(r') \Gamma(r', \omega) E_b(r')$$

- LN technique ignores local gradients (and higher order derivatives) of the internal field
  projection of the background field onto a semi-analytic 3x3 scattering tensor at each internal point

- Approximation was extended to rectangular prisms of arbitrary aspect ratio
  "building blocks" for more realistic applications (Groom et al 1993)

Inductive Modes

- By design, LN accurate only when the local gradients of the internal field are insignificant
  e.g. strong inductive coupling of source and scatterer
- Inductive Non-linear (ILN) Approximator incorporates the field gradients
  12x12 system expressible in terms of analytical and numerical quadratures

- spatial gradients of integral equation

$$\nabla E(r) = \nabla E_b(r) + Q\nabla\int dr^{/} G(r,r^{/})\cdot E(r^{/})$$

- Taylor expansion

$$\nabla^{*} E(r) \approx \nabla^{*} E_b(r) + Q\nabla^{*}\int dr^{/} G(r,r^{/})\cdot\left[E(r) + \nabla E(r)\cdot(r^{/} - r)\right]$$

- Inductive LN (ILN) operator

$$\begin{bmatrix} E(r) \\ \nabla E(r) \end{bmatrix} = T(r,\omega)\begin{bmatrix} E_b(r) \\ \nabla E_b(r) \end{bmatrix}$$

Multiple Interactions

- For most geological models, the effects of interactions must be considered
- LN is a single target technique thus methods for multiple targets must be incorporated

Near Field Interaction

- model structures in electrical contact
- current flow is enforced across anomaly boundaries including conductivity and/or permeability discontinuities

$$E_{NF}^{s}(r) = \sum_{i=1}^{n} \int_{V^{(i)}} dr' \, G(r, r') \cdot$$

$$\left[I - Q^{(i)} \sum_{j=1}^{n} L^{(j)} \right]^{-1} E_b^{(i)}, \quad L^{(j)} = \int_{V^{(j)}} dr' \, G$$

Far Field Interaction

- recommended for model structures at interim distances from each other or where interactions are believed to be important
- response accounts for first order backscatter between anomalies

$$E_{FF}^{s}(r) = \sum_{i=1}^{n} \int_{V^{(i)}} dr_i^{\prime} G(r, r_i^{\prime}) \cdot \Gamma^{(i)} \cdot \left[E_b^{(i)} + \sum_{j \neq i}^{n} \int_{V^{(j)}} dr_j^{\prime} G(r_i^{\prime}, r_j^{\prime}) \cdot \Gamma^{(j)} E_b^{(j)} \right]$$

Magnetic Effects

- consider simultaneous variations in electrical conductivity and magnetic permeability for a time-varying source excitation
- Non-Linear Magnetic Modelling and susceptibility effects in current channelling

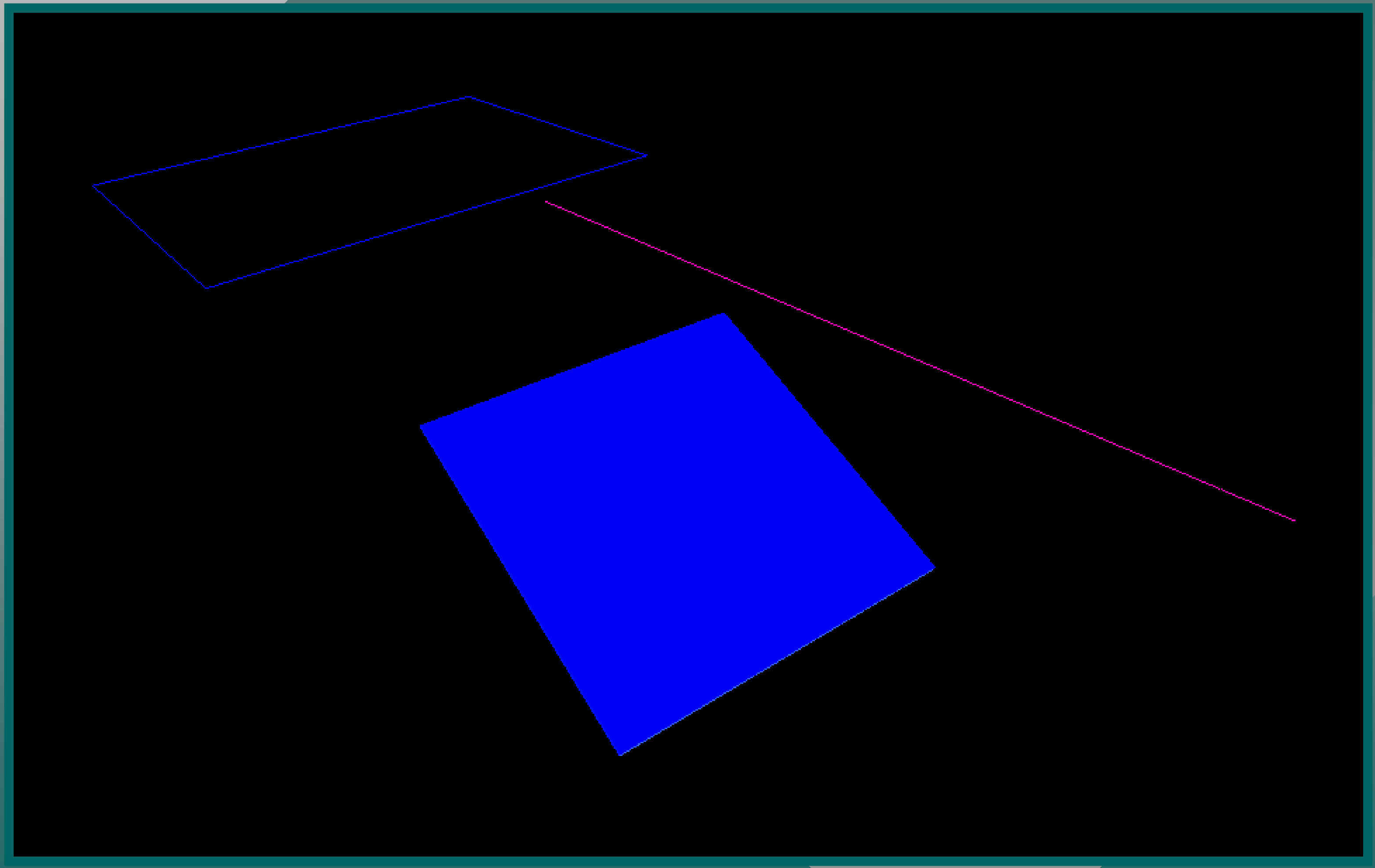
Polyhedra

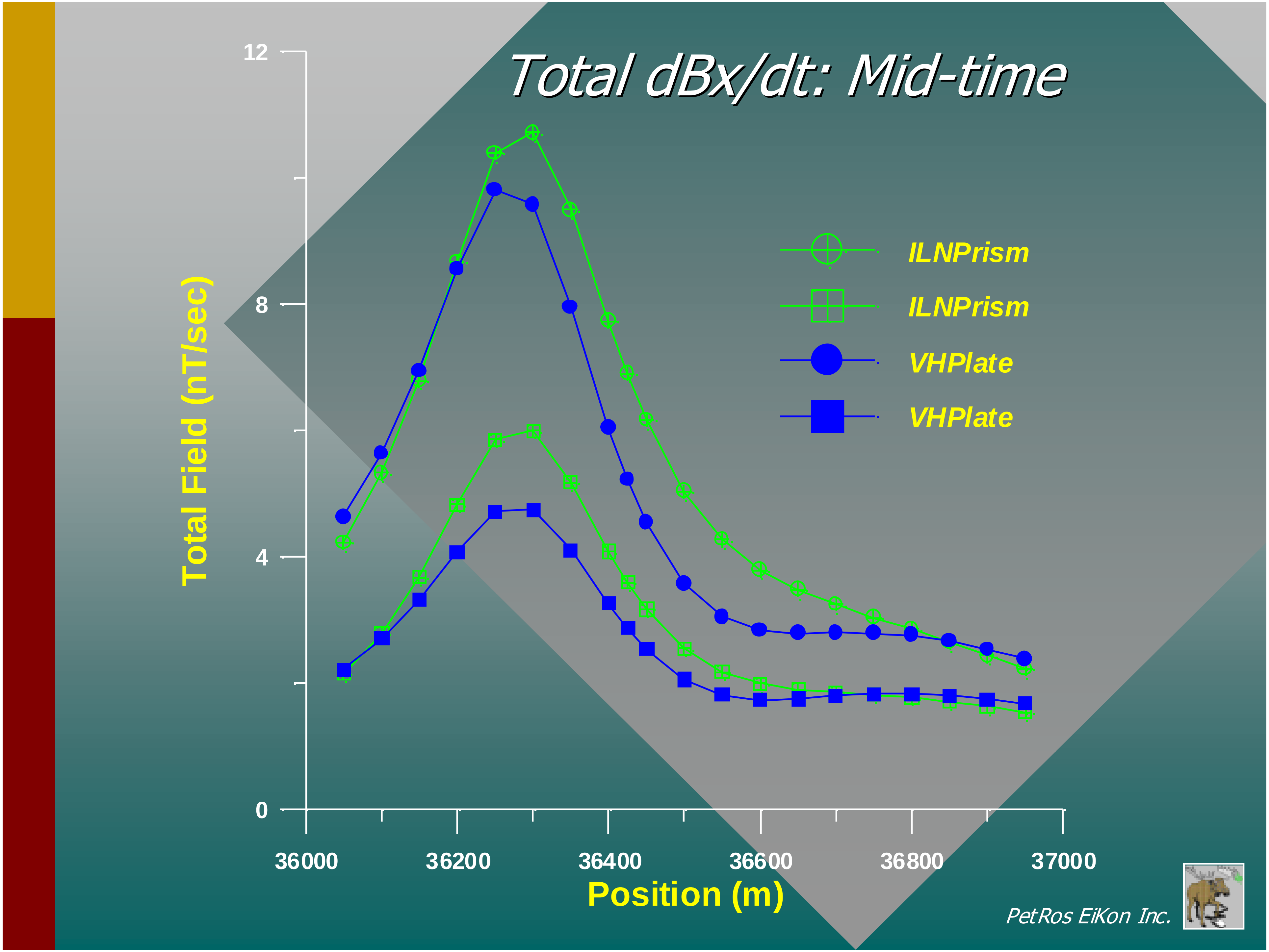
- the LN theoretical development, and its extensions to inductive modes, multi-body problems and magnetic effects is independent of scatterer geometry
- it is in the implementation of the theory where the geometry of the scatterer plays a significant role (particularly in the evaluation of the scattering tensors)

Model Results and Interpretation

- models arise from an interpretation study of time domain data collected in northern Quebec
- exploration targets are massive or disseminated sulphide ores embedded beneath large peridotite structures in a host material of volcanic sediments

Sulphide Target in Isolation





Total dBx/dt: Mid-time
Total Field (nT/sec)
12
8
4
0
36000
36200
36400
36600
36800
37000
Position (m)
ILNPrism
ILNPrism
VHPlate
VHPlate
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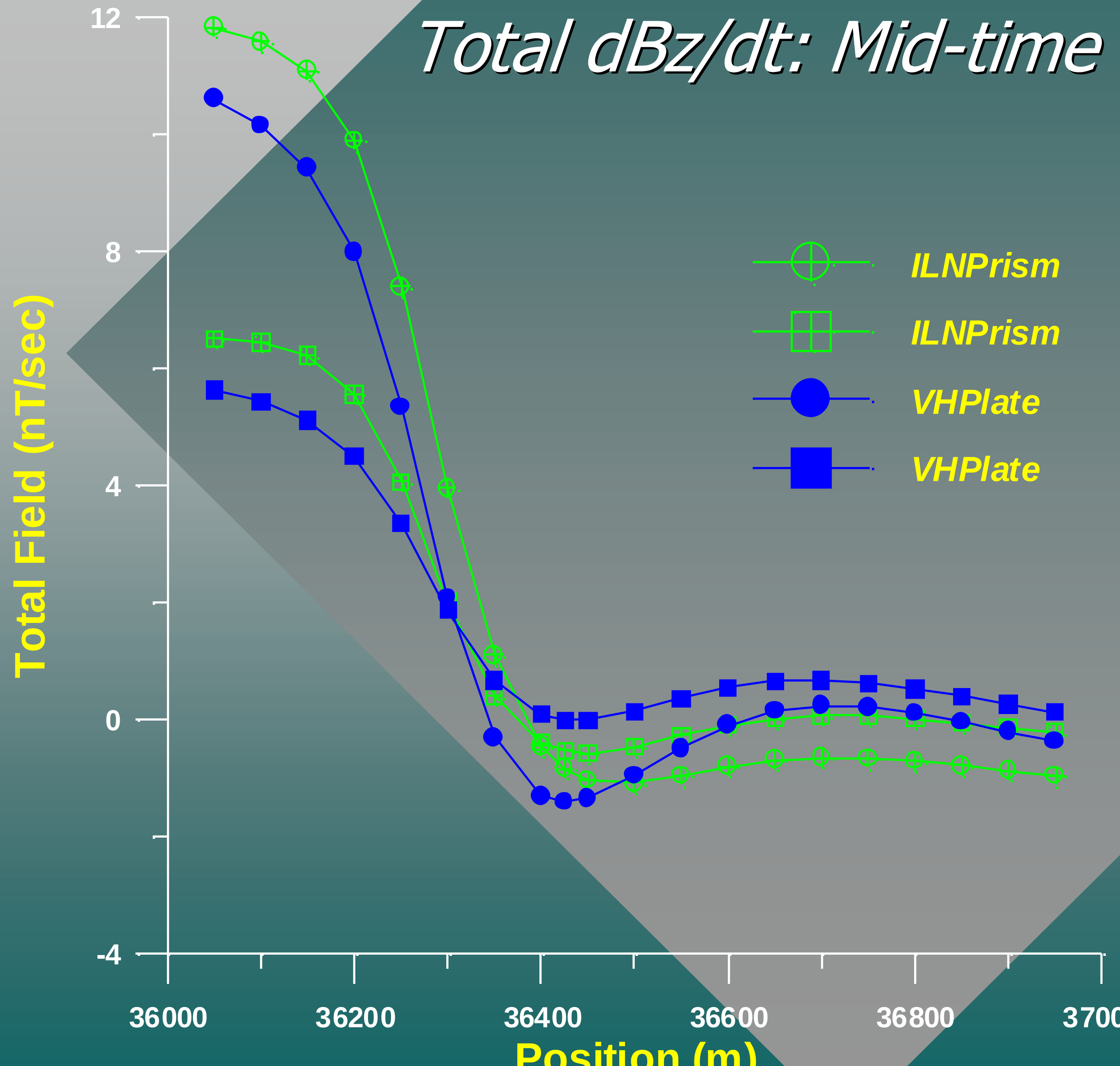
Total dBz/dt: Mid-time



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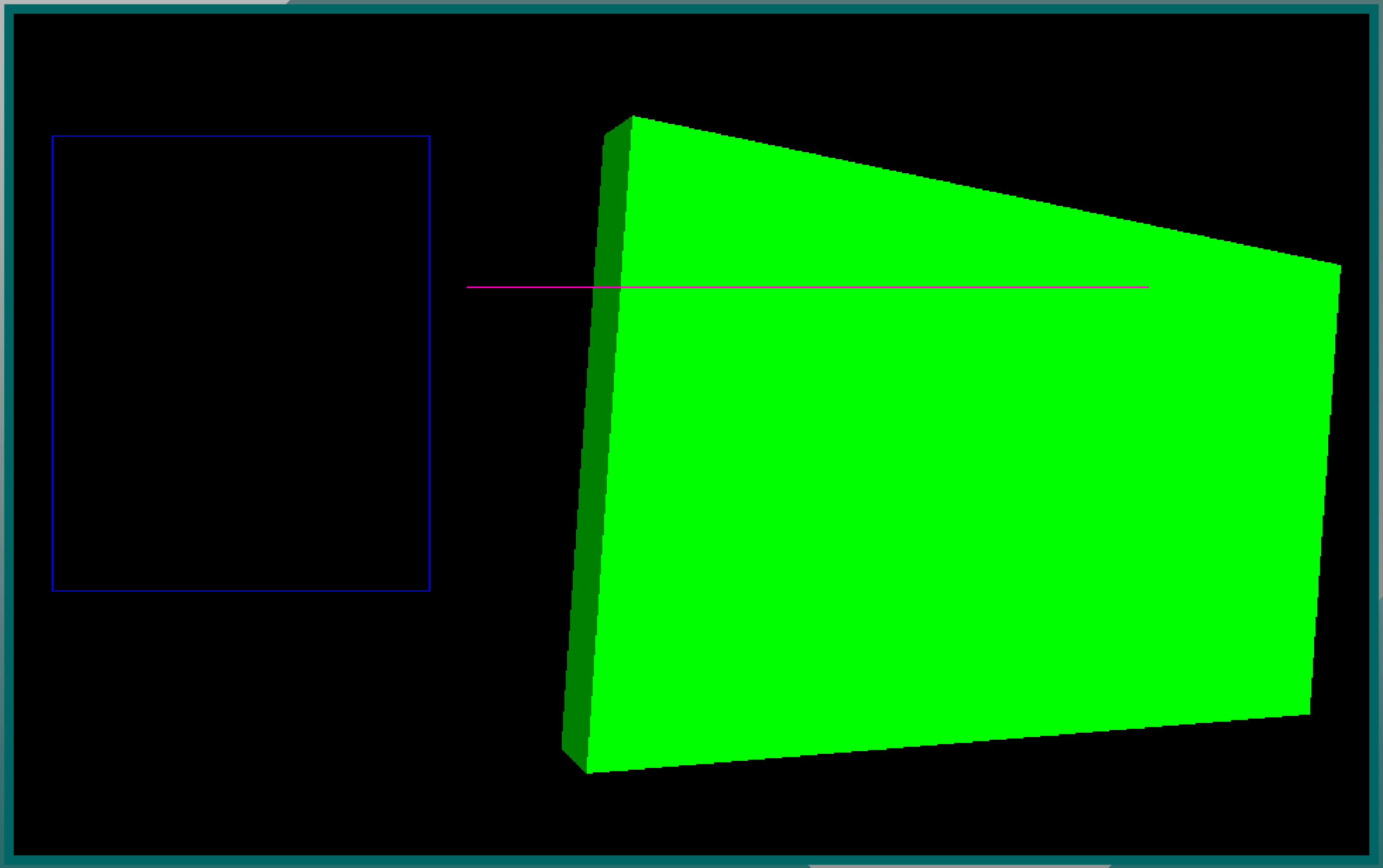
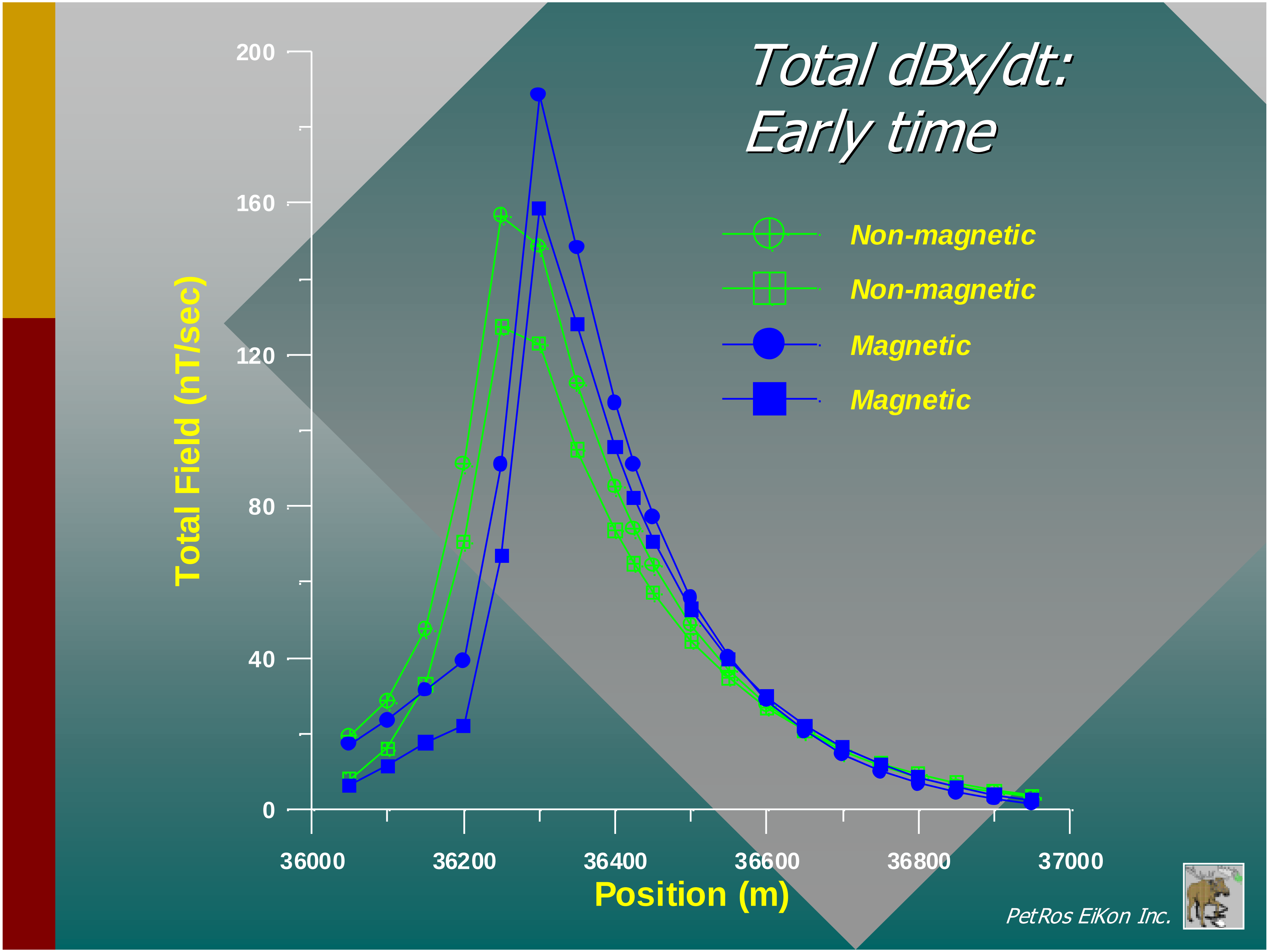
Peridotite Structure in Isolation




Total dBx/dt:
Early time
Non-magnetic
Non-magnetic
Magnetic
Magnetic
Total Field (nT/sec)
0
40
80
120
160
200
36000
36200
36400
36600
36800
37000
Position (m)
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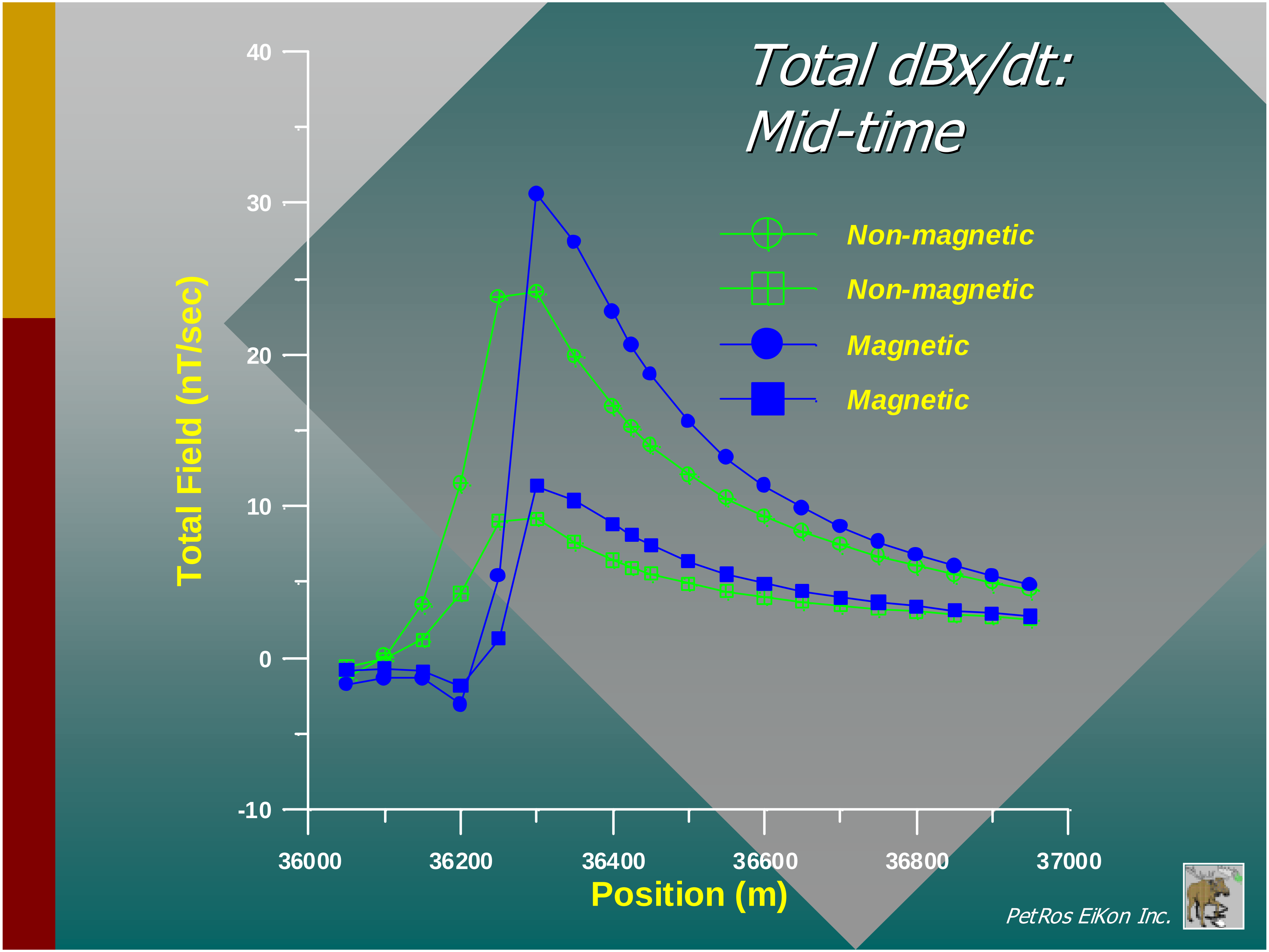
Total dBx/dt:
Mid-time
Non-magnetic
Non-magnetic
Magnetic
Magnetic
Total Field (nT/sec)
40
30
20
10
0
-10
36000
36200
36400
36600
36800
37000
Position (m)
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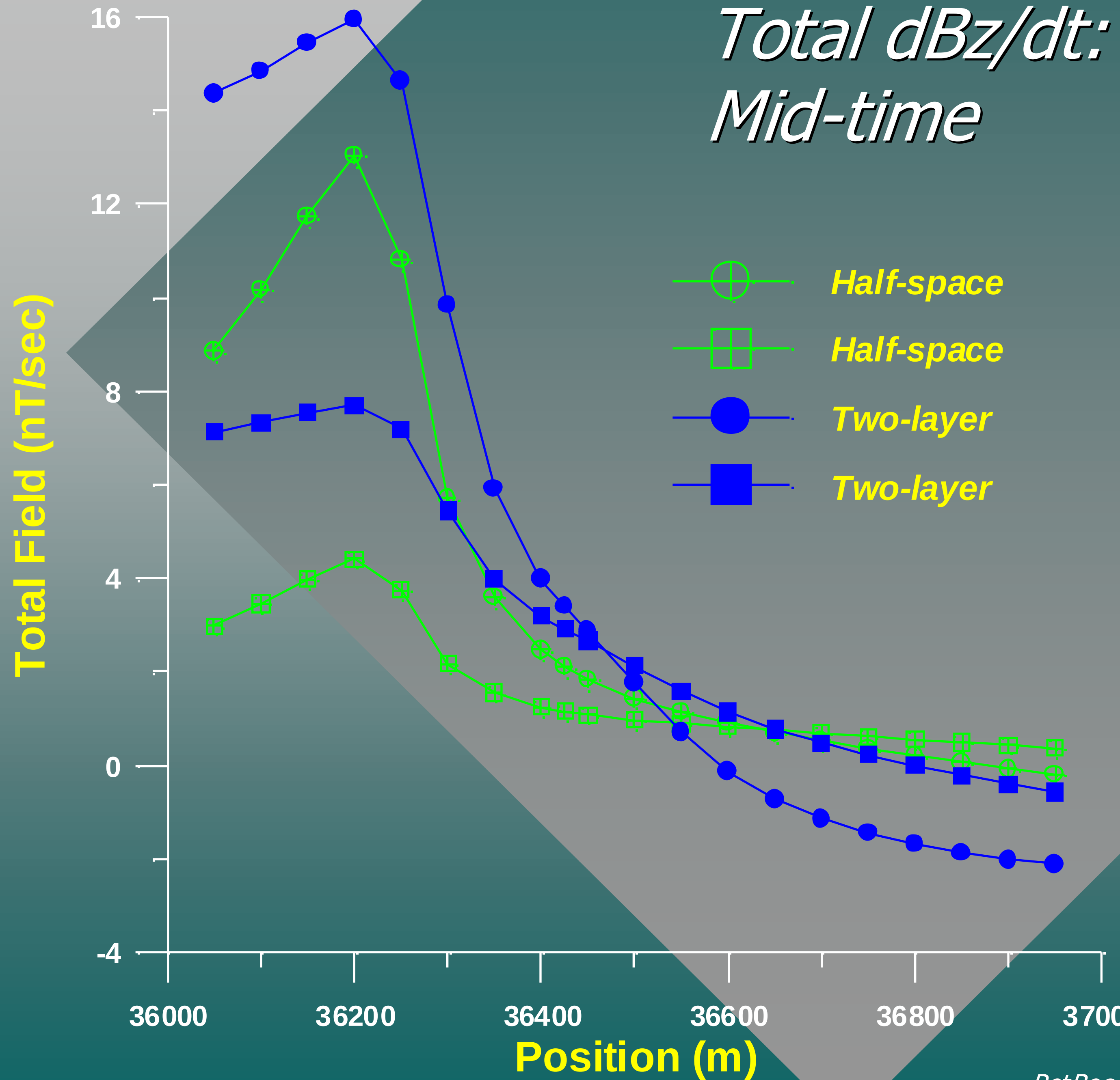
Total dBz/dt: Mid-time



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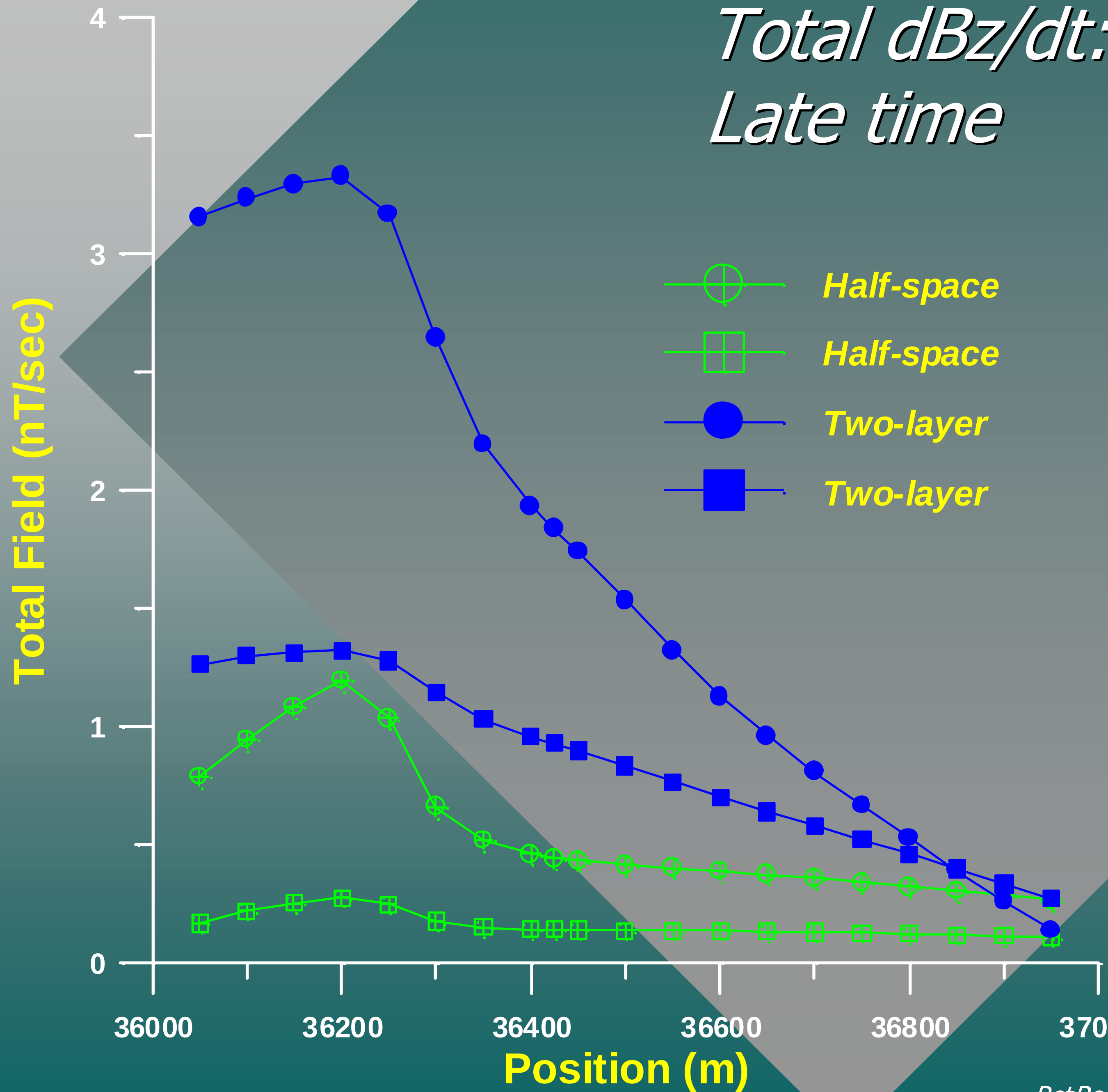
Total dBz/dt: Late time



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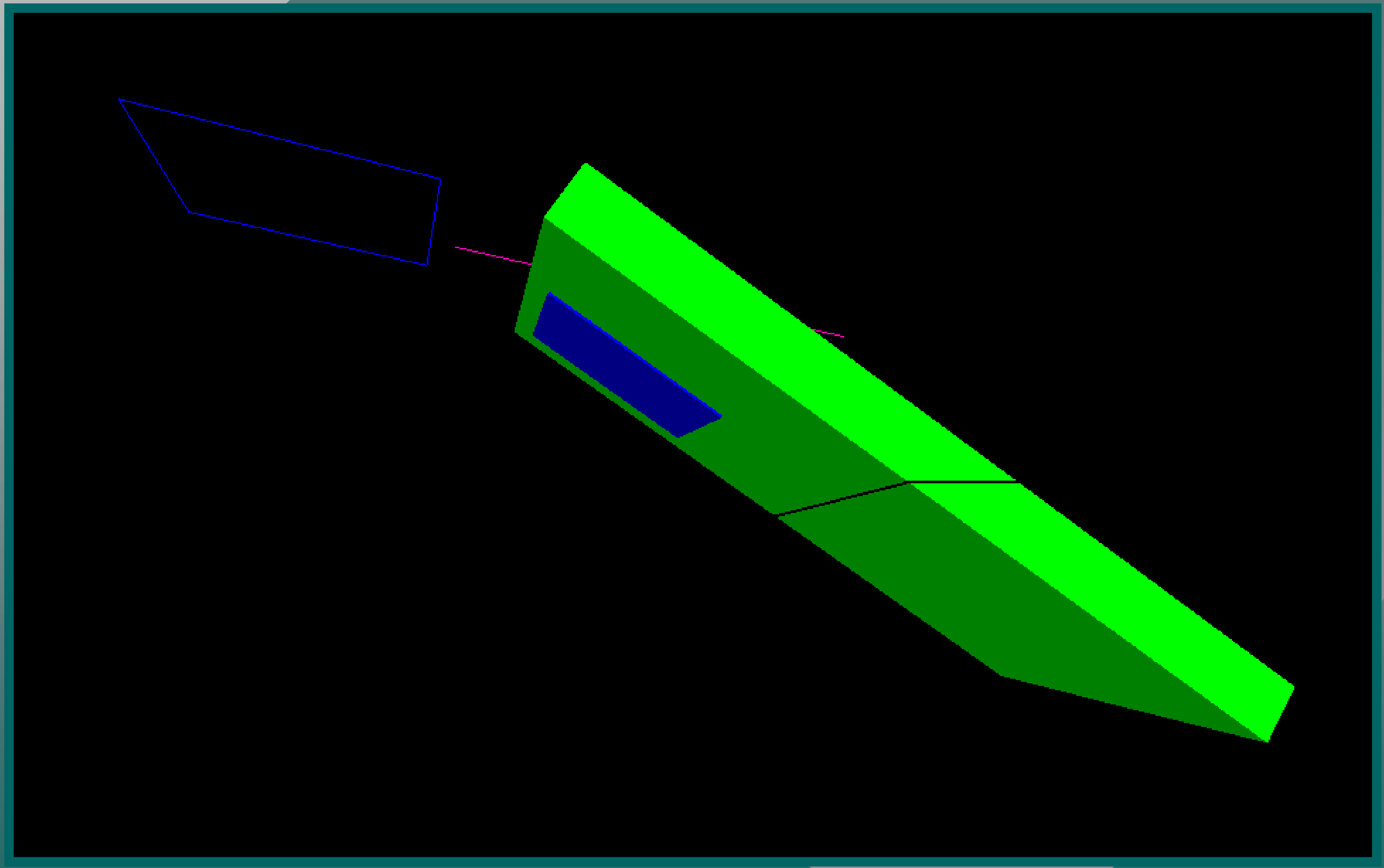
Combined Ore/Peridotite Two Layer Model



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Conclusions

- extended developments of the LN technique hae proven to be extremely fruitful in the interpretation of real data