用信赖域方法对各种时间域电磁数据的反演

Time Domain Inversion Incorporating Various Data Strategies with a Trust-Region Method

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摘要 Introduction

位于发射器线圈内的接收器采集的时间域电磁数据有时对深部地质结构的灵敏度有限。一些设备测量的线圈外数据比线圈内数据质量更好。为了能够同时结合线圈内外的数据，以找出满足实际地质约束条件更准确可靠的地质背景分层模型，我们提出一种带约束条件的信赖域方法，可同时反演多个测点和多个分量的时间域电磁数据。这种信赖域方法具有较快的收敛速度，并可以利用已知的地质信息为约束条件。也使可能的分层模型的数量的大大地减少。

Inside-loop time domain data may be of limited sensitivity to deep geological structures. Some TEM systems collect outside-loop data of quality better than inside-loop data. To process TEM data incorporating both inside-loop and outside-loop data, we developed a constrained trust-region method to jointly invert the data of multiple stations and multiple components. It enables us to explore the importance of utilizing multiple data elements to provide accurate and reliable results. The trust-region method has a fast convergence rate and can incorporate known geological information, leading to large reductions in the number of suitable models.

信赖域方法 Trust-Region Method

所采用的信赖域方法为带约束的非线性最小二乘法。在反演过程中，利用泰勒级数展开式作为目标函数的二阶近似。利用投影梯度法，确定一个初始点，在该点目标函数的二阶近似式有足够的减少。利用投影梯度法更为有效，因为几个约束条件可以一次行的同时添加。第二阶段的计算，进一步寻求如何减少目标函数的二阶近似，目的是为了加快反演的收敛速度，附加约束条件为，落在其边界的参数在第二个阶段保持不变。

Our trust region method solves a non-liner constrained least-squares minimization problem. During the inversion process, we construct a quadratic approximation to the objective function utilizing the Taylor series expansion. As the second stage of the step computation, a further reduction of the quadratic model is sought to enhance the convergence of the inversion with the additional restriction that the parameters on their bounds are kept fixed throughout the second process.

模拟数据反演 Synthetic Data

模拟勘测设计中，发射器是一个以（0，0）为中心400 × 400米的线圈。接收器位置分别处于每隔100米的南北线上，从0N 到800N（200N除外，因这恰好是北侧线圈的位置）。系统的基频设为30赫兹，并有20断电时间窗口。反演的初始模型为200 Ωm 半空间. 单测点数据反演，只在两个测点的结果较好：300N，700N。在其他测点模型不拟合数据。多测点数据反演，使用所有八个测点数据，获得非常好的结果。模型拟合数据且接近实际模型。反演模型接近实际模型且拟合数据（图1）。

A 400 x 400 m loop centered at (0, 0) was used. Receiver locations were every 100 m on a north-south line from 0N to 800N (except at 200N where the north side of the loop is located). The base frequency of the system was 30 Hz, and there were 20 off-time channels. The starting model of the inversion is a 200 Ωm half-space. A single-station inversion finds a good result only at two locations: 300N and 700N. At the other locations, the inverted models do not fit the data. In a multi-station inversion using all eight stations, excellent results were obtained. The model fits the data well and is close to the true model (Figure 1).

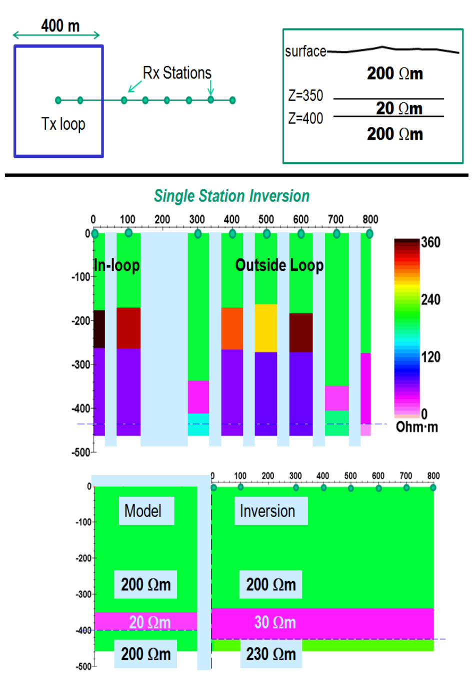

图1: 模拟数据反演结果.
Figure 1: Inversion results of synthetic data.

实测数据 Real Data

采用了一个带有TEM 67发射器 Geonics 公司的PROTEM系统,进行地面时间域电磁勘测. 沿着南北两条线，线距100米.发射器线圈为400 x 400米，位置固定。基频是30赫兹，测量x，y，z三个分量.初步正演建模得到的一个四层模型被用来作为四层信赖域反演的初始模型。反演中用的是最靠南的11个测点的垂直分量数据，它们离线圈中心1300至2300米以南，偏离线圈中心100米。反演模型与整个勘测的数据拟合,与勘测区钻探资料一致(图2)，也与该测区内其他设备MaxMin 及VLF-R 勘测所提供的信息一致.正演和反演工作中，接收器的带宽设为17 kHz. 位于发射线圈中心2公里以南的测点对苏佩组较为敏感(图3)，而位于发射线圈中心的测点对苏佩组并不敏感. 这表明与发射线圈较远的测点比线圈内测点能更好地反映深层的结构.

A PROTEM system using a TEM 67 transmitter (Geonics) was used to collect a fixed loop TEM survey on two north-south lines, 100 m apart. The base frequency was 30 Hz and three components were collected. Preliminary modeling resulted in a four-layer model. This model was then used as the starting model for a trust-region inversion on Hz collected at 11 stations1300-2300m south of the loop centre and 100 m off-centre of the loop. The inverted model fits both Hz and Hx well across the entire survey. The inverted model is consistent with the drill results just south of the survey area(Figure 2). The resistivity 123 Ωm of Moenkopi, the top layer, is close to resistivity determined from VLF-R and MaxMin data which were collected at the site. Modeling and inversion work was performed with a 17 kHz bandwidth for the receiver. The data of locations 2 km south of the transmitter loop center are sensitive to the Supai Group (Figure 3). The data at the loop center are of limited sensitivity to the Supai Group, indicating that large offset out-of-loop data may resolve deeper structures better than inside-loop data.

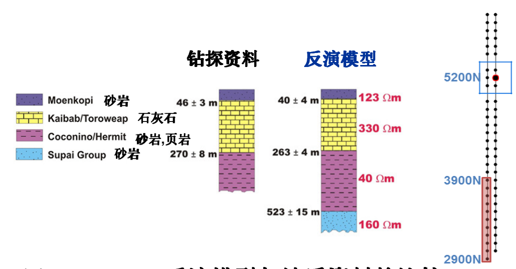

图2 (Figure 2):反演模型与地质资料的比较
Comparison of Inversion Model with Geology

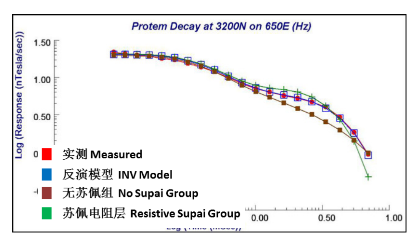

图3 :位于发射线圈中心2公里以南的接收器对苏佩组较为敏感.
Figure 3: *The locations 2 km south of Loop Center is sensitive to Supai Group*

结论 Conclusion

可以采用信赖域反演方法处理各种时间域数据，以得到一个合适的地质背景分层模型。数据可以来自多个测点，也可以是不同的分量数据。对不同数据组合的反演有很多好处，包括提高反演过程中的信噪比，也使要寻求的分层模型的数量的大大地减少。

It is possible to apply multiple time domain data elements to a trust-region inversion for a single multi-layer model. Such multiple data elements can be data from multiple stations and/or data from different data components. The extension to multiple data components has a variety of benefits including the ability to enhance the signal to noise characteristics in the inversion process and large reductions in the number of suitable models.

参考文献 References

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