Airborne electromagnetic imaging for critical-minerals resource assessment

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SUMMARY

Mineral resource assessments are fundamentally grounded in data – specifically data that differentiate regions prospective for a resource from those that are not. The Earth Mapping Resources Initiative is collecting baseline geophysical data over targeted areas of the United States to support upcoming critical mineral assessments. Approximately 30,000 line-kms per year of airborne electromagnetic (AEM) data are being collected as part of this effort. In the first year, surveys in Nevada, Alabama and Alaska will be carried out to inform national-scale graphite and lithium assessments. AEM surveying for graphite is one of the few cases where geophysics can directly map the resource of interest; we describe AEM surveys to be flown over two of the primary graphite resources in the nation. We also describe a regional survey focused on lithium brines and clays, where AEM models will be used to constrain deposit genesis models and to narrow the currently vast region considered prospective for lithium. We highlight aspects of the survey design and show preliminary results for those surveys that have already begun flying.

Key words: airborne electromagnetic, critical minerals, lithium, graphite

INTRODUCTION

The Earth Mapping Resources Initiative (EarthMRI) is a partnership between the United States Geological Survey (USGS) and State Geological Surveys to modernize surface and subsurface geological mapping for the nation and to identify areas with potential for undiscovered critical minerals. Components of the program include airborne geophysical surveying, geologic mapping, and geochemical sampling. These data will ultimately be used to support mineral resource assessments and prospectivity mapping within a mineral-systems framework (Wyborn et al., 1994).

Geophysical surveying under EarthMRI, begun in 2019, was initially limited to aeromagnetic and radiometric data. Airborne electromagnetic (AEM) data acquisition began in 2022 and is currently acquiring ~30,000 line-km of data annually. AEM surveys to date have focused on lithium, a critical component of rechargeable batteries, and graphite, used for lubricants, batteries, and fuel cells.

Two AEM surveys are being flown over high-grade metamorphic terranes prospective for graphite: 1) the Alabama graphite-vanadium belt within the Southern Appalachian Mountains and 2) the Kigluaik, Bendeleben, and Darby Mountains of the Seward Peninsula, Alaska. The latter hosts the world-class Graphite Creek deposit, while the former is an area of both historic graphite mining and ongoing resource development. While graphite, with its enhanced electrical conductivity, is the primary electrical target, both survey areas host a wide range of other critical mineral commodities.

In addition, a multi-year regional AEM survey is being flown over the Basin and Range (B&R) province of Nevada and Oregon. This survey is focused on lithium contained within electrically conductive basin brines and clays. Worldwide lithium production comes primarily from pegmatites, but interest in sediment-hosted lithium resources has led to considerable exploration and development, predominantly in the B&R, which also includes the first lithium-brine mining operation in North America. As nearly half of the B&R is considered prospective for lithium, these surveys aim to better understand the components and controls on basin lithium formation, and in doing so reduce the exploration space for this class of deposits. Beyond lithium, the B&R province contains a range of deposits that may host critical minerals. Porphyry Cu-Mo-Au and Climax type deposits, for example, are known throughout the B&R and may contain beryllium, fluorine, tungsten, and gallium. These deposits are commonly characterized by conductive quartz-sericite-pyrite alteration halos, ideal targets for AEM.

METHOD AND RESULTS

The 11,000 line-km B&R survey spans several tectonic domains, requiring a flexible survey design with variable flight azimuth crossing different structural domains. To optimize survey design, Quaternary faults, mapped strike directions, and geologic cross-sections were examined to define three distinct flightline azimuths that vary throughout the survey area to best capture local structural trends (Figure 1). A nominal 5 km line spacing was chosen to balance the large survey area with a need for continuity between adjacent sections. In areas of known lithium resources, more densely spaced flightlines were flown to facilitate investigations into lithium process models (Ball et al., 2023; Bradley et al., 2013) and to support detailed geologic mapping activities. Finally, as the depth scale of interest ranges from ~5 m to 500 m (shallow sedimentary layers to deep basement conductors), a hybrid system approach was employed using three systems with differing moment, loop size, waveform, and base frequency (Murray et al., 2023). This hybrid approach allows for superior depth-of-investigation in flat areas using a large, high-moment system while permitting better altitude control in areas of steep terrain using a lighter, smaller system.

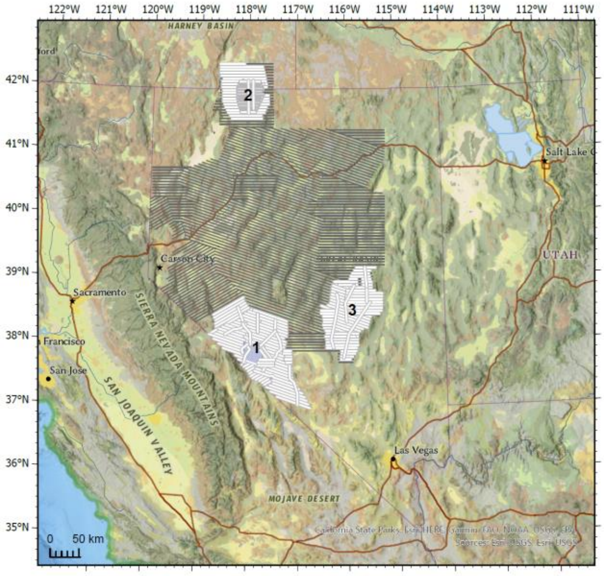

Figure 1. Nominal flight plan for regional AEM survey in Nevada. White lines in areas 1-3 were flown in 2023. Variable line azimuths capture changes in structural trend.

The dynamic range within the measured data is reflected in the model domain by a pronounced contrast between resistive basement and bedrock exposed in the ranges and thick conductive sedimentary packages in the intervening basins (Figure 2). Depth of investigation is ~500 m over the ranges, reducing to ~300 m in the basins, and as little as 100 m over clays and brines within closed basins. Induced polarisation (IP) effects are occasionally observed near range fronts, where thin conductive sediments overlie rocks. More pronounced are fault-bounded blocks of limestone and dolomite that exhibit strong IP effects including fully negative decay curves. As of this writing, flying is 2/3 completed, while another 10,000 line-km of flying is being contracted for 2024.

The AEM survey in Alabama is focused upon an area of historic mining and ongoing development in the graphite-vanadium belt but includes a halo of widely spaced lines designed to map the structural framework of this complex geologic terrane (Figure 3). The survey area, situated between the major metropolitan areas of Montgomery and Birmingham, is heavily built up, requiring a detailed survey design to both avoid airspace restrictions and minimise the impact of roads, powerlines, pipelines, and electrical substations. As of this writing, data collection has just begun. AEM data collected along a pair of test lines shows good agreement with ground geophysical data (transient electromagnetic and electrical resistivity tomography profiles) collected nearby. Inverted resistivity models from the AEM test line data show strong variability, with pronounced basement conductors (~1 Ω·m) over mapped graphite-bearing lithologies and a strong resistivity contrast at the edge of the mapped graphite belt (Figure 4).

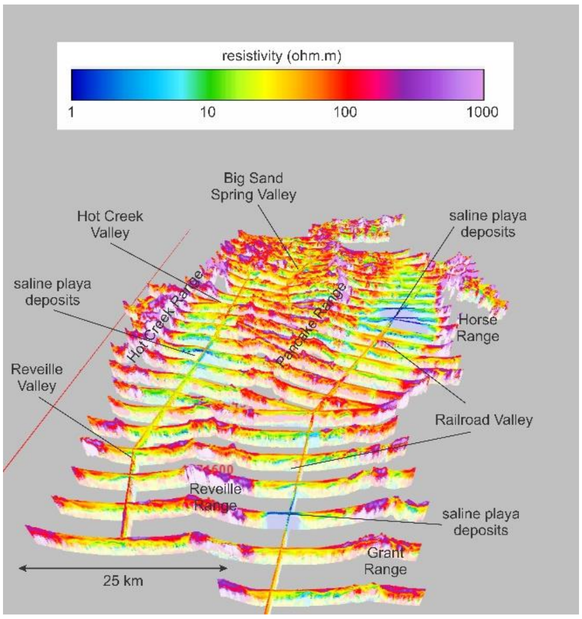

Figure 2. Perspective view of the Railroad Valley block looking north (area 3 in Figure 1). Strong conductors reflect clays and brines within closed valleys.

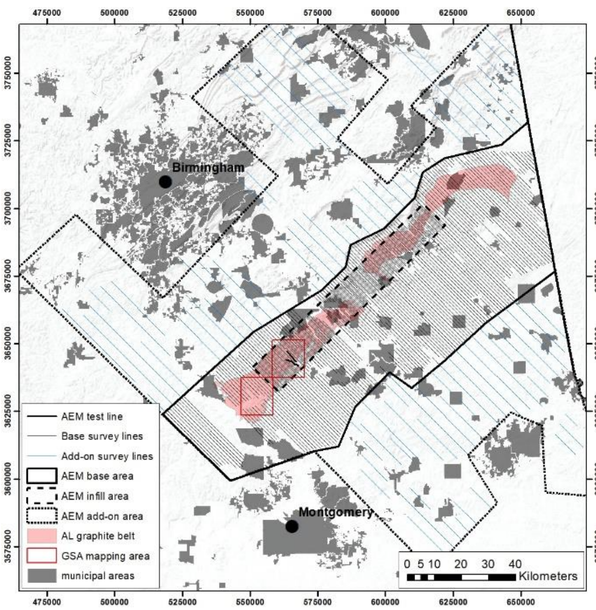

Figure 3. Flight plan for regional AEM survey in Alabama. Graphite-vanadium belt indicated in red.

The Alaska AEM survey, not contracted as of this writing, is the most remote of the surveys, covering a vast area of high-grade metamorphic rocks (Figure 5). Analogous to the Alabama belt, graphite in Alaska is contained within narrow, elongate stringers that can be traced for 10s of kilometers along strike. At the Graphite Creek deposit, these stringers contain lenses of massive graphite up to 1 m thick and with grades approaching 50% (Case et al., 2023). A commercial AEM survey over the Graphite Creek deposit area imaged several sub-vertical conductors aligned with regional faults and extending for more than 15 km along strike. A goal of the Alaska AEM survey is to cover the entire region of high-grade metamorphic rocks (6,000 km^2) and to understand the geologic and tectonic controls on graphite formation and concentration in metamorphic terranes.

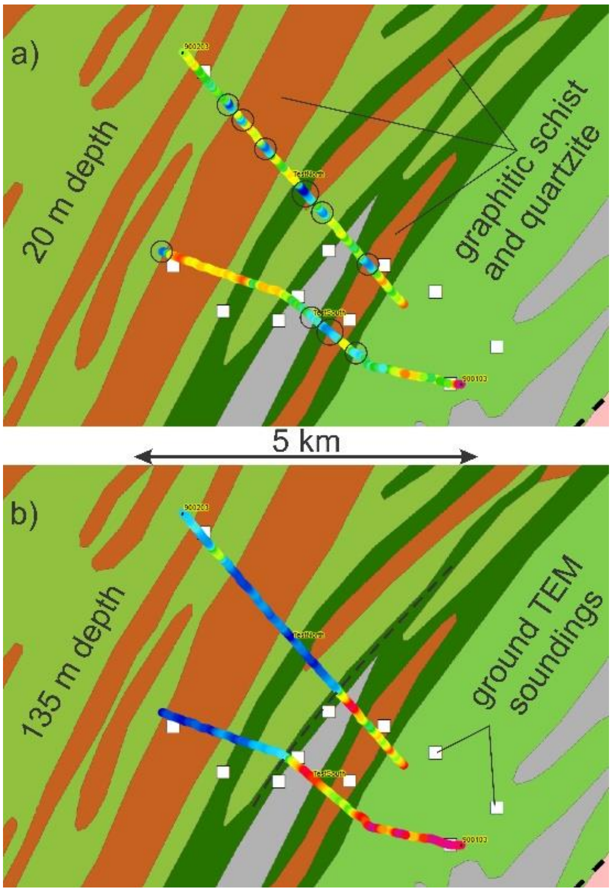

Figure 4. Inverted resistivity over the Alabama Graphite-Vanadium belt at (a) 20 m and (b) 135 m depth. Color scale is as in Figure 2. Note correspondence between graphitic schist and quartzite (brown) and shallow conductors in a) and abrupt change in resistivity along the eastern margin of the belt in b). Dark and light green units are amphibolite biotite gneiss, respectively. Gray unit is non-graphite bearing mica schist.

CONCLUSIONS

AEM surveys are an effective way to collect data at the scales needed to support regional and national-scale resource assessments. The initial AEM investment by EarthMRI has focused on 'low-hanging fruit,' including mapping graphite in metamorphic terranes and mapping areas prospective for lithium brines and clays, where imaging the lithologic and structural framework directly informs conceptual models for deposit formation. Future EarthMRI AEM surveys will expand upon these findings, both in terms of evaluating other regions for these same resources and in expanding to cover additional mineral systems (e.g., mafic magmatic and volcanogenic seafloor systems) known to host critical mineral commodities.

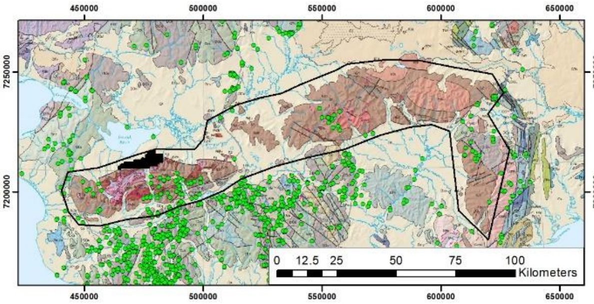

Figure 5. Alaska graphite survey area (black polygon). Filled black polygon denotes exploration AEM survey flown over the Graphite Creek deposit. Green symbols are mineral occurrences from the Mineral Resources Data System (primarily gold within the Nome mining district).

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