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Shipboard Surveys Track Magnetic Sources in Marine Sediments— Geophysical Studies of the Stono and North Edisto Inlets near Charleston, South Carolina

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1. Abstract

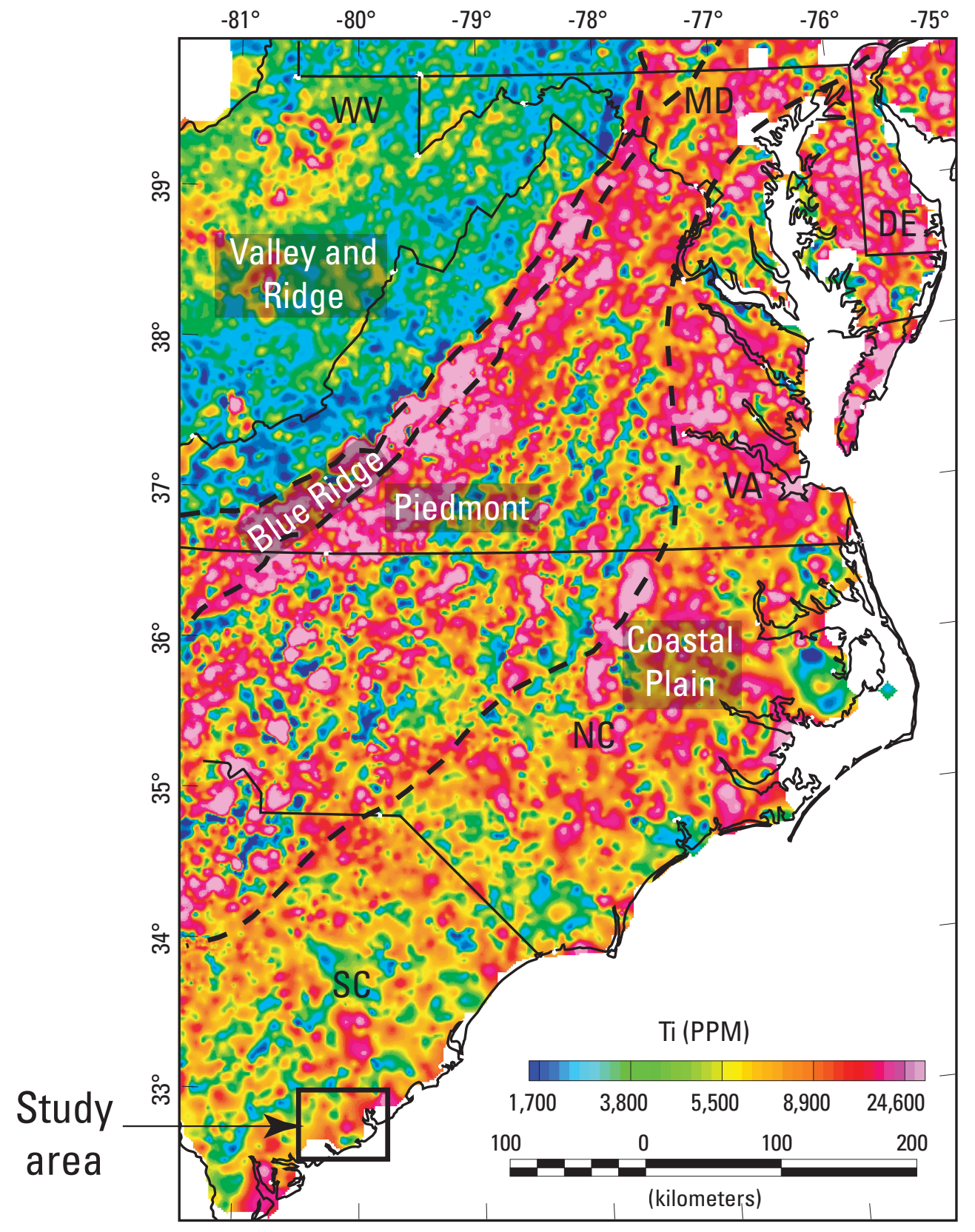
Magnetic field data are traditionally used to analyze igneous and metamorphic rocks, but recent efforts have shown that magnetic sources within sediments may be detectable, suggesting new applications for high-resolution magnetic field data. Candidates for such sources include heavy mineral sands transported from upland sources, biogenic magnetite, and certain forms of glauconite. Magnetic field surveys can be used to map distributions of these sediments with much denser and widespread coverage than possible by sampling, providing constraints on the composition, deposition, and transport of local sediments. However, as sedimentary sources are likely to be much weaker than their crystalline counterparts, mapping requires the sensor to be relatively close to the source, and filtering approaches are needed to distinguish signals from both system noise and deeper basement features.

Marine geophysical surveys conducted in July, 2010, over the Stono and North Edisto River inlets and their riverine inputs south of Charleston, S.C., used a total field cesium magnetometer and 900 kilohertz (kHz) sidescan sonar. In these tidally influenced estuarine environments, unconsolidated Quaternary sediments of 0–10 meters (m) thickness overlie an indurated Tertiary substrate. Calm survey conditions allowed the towing of sensors 2–20 m above the seabed with background magnetometer variations of less than 0.5 nanotesla (nT) and a measurement spacing of less than 0.4 m. Isolated anomalies associated with metallic objects such as crab pots or other anthropogenic debris were filtered in part by comparisons to the high-resolution sonar.

Spectral processing to highlight short-wavelength magnetic anomalies revealed 10- to 40-m-wide, 1- to 6-nT magnetic anomalies associated with shallow, sand-covered seabed as indicated by the sidescan sonar data. These anomalies are distinct from system noise but are too narrow to represent basement features. The anomalies are observed mostly in shallow areas where river sediments originating from upland areas enter the inlets. In contrast, the anomalies are not observed near or within the younger, coast-parallel Kiawah River, where sedimentary inputs are primarily from closer surrounding areas.

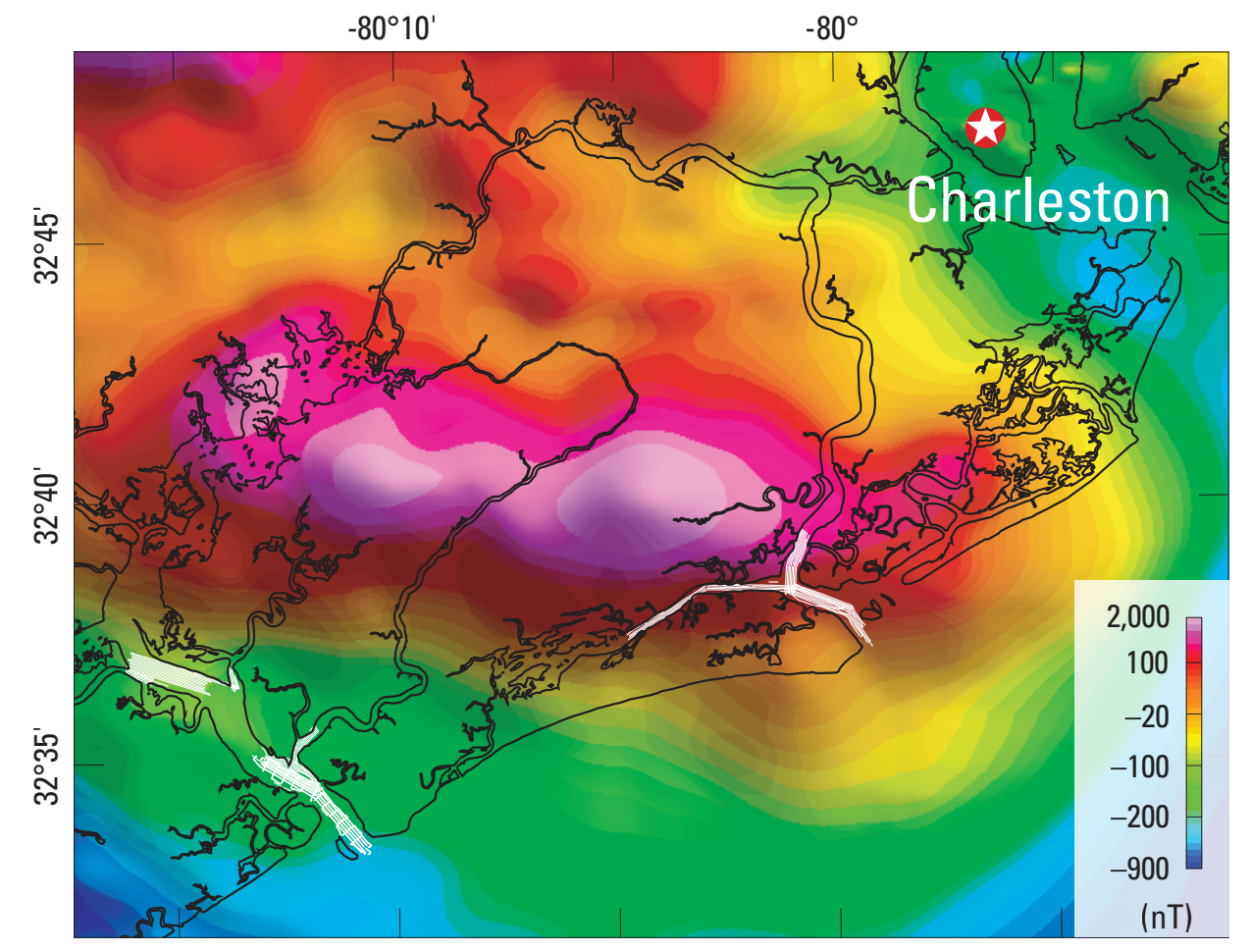
Previous studies do not indicate biogenic magnetite or glauconite within the strata underlying the survey area, but rivers and reworked Pleistocene barrier island sands supplying the Charleston area inlets originate from within the metamorphic Piedmont and Blue Ridge terranes. Grab samples from the North Edisto River contain trace amounts of hematite, maghemite, ilmenite, and magnetite, as well as garnet, epidote, zircon, and rutile. If the sands are sorted by prevailing currents, greater concentrations of heavy mineral sands are likely to reside a few centimeters below the seafloor and could generate the observed magnetic anomalies. The presence of anomalies in inlets connected to upland areas and the distribution of stream sediment titanium (Ti) over the Atlantic Coastal Plain suggest that the magnetic anomalies are generated by Ti- and iron (Fe)-rich heavy mineral sands ultimately originating from the Piedmont and Blue Ridge, which are then reworked and concentrated by tidal currents. The distribution of these sands within each of the inlets reflects the local hydrodynamic environment.

2. Titanium in stream sediments



Stream sediments collected and analyzed as part of the National Uranium Resource Evaluation (NURE) program show areas of enhanced Ti that are aligned with the metamorphic Blue Ridge and Piedmont provinces, outlined in black dashed lines (defined by Fenneman and Johnson, 1946). Titanium-rich sediments most likely originate from these provinces and have been transported and reworked throughout Coastal Plain sediments. Data compiled by Smith (1997).

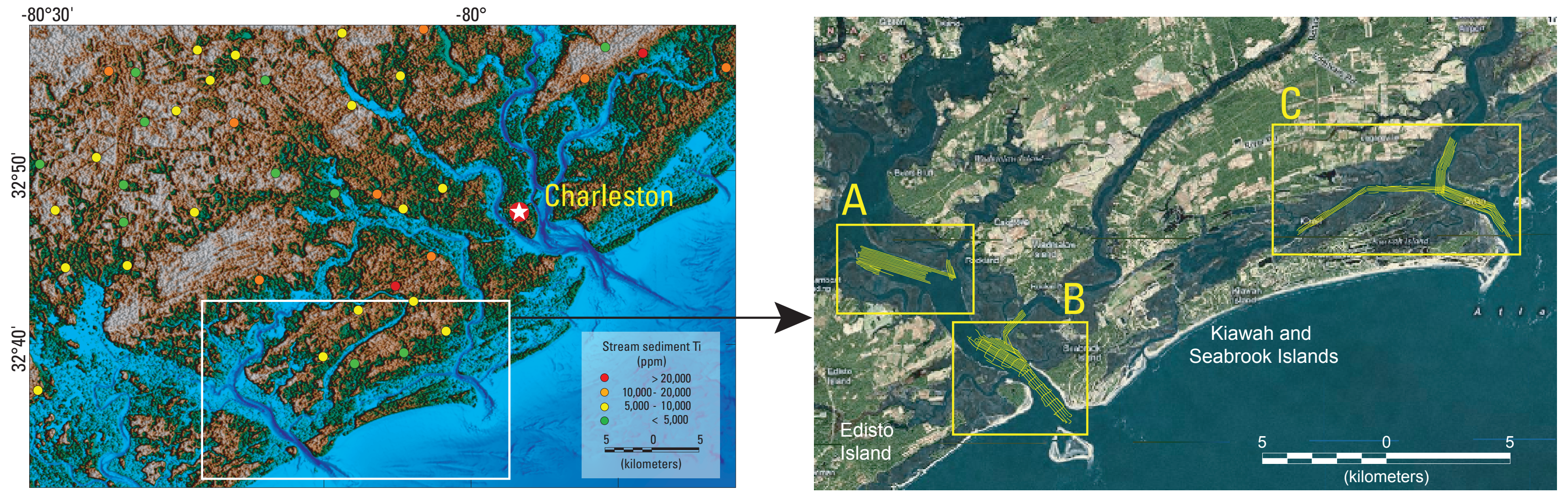
3. Regional magnetic field



Regional magnetic data were collected between 1958 and 1978 using airborne methods from altitudes of about 150–450 m, with line spacing ranging from 800 m to 4,800 m (compiled by Daniels, 2005). Because magnetic anomalies attenuate with distance from the source, magnetic data collected at these altitudes typically represent sources with stronger magnetic properties such as igneous and metamorphic rocks that comprise the crystalline basement. Near Charleston, the "magnetic basement" represents Jurassic basalts at roughly 1-kilometer (km) depth (Behrendt and others, 1983; Daniels and others, 1983). Weaker signals generated by sedimentary sources are not apparent in the aeromagnetic data.

White lines represent shipboard magnetic surveys; black lines delineate the coastline and waterways.

4. Shipboard geophysical surveys



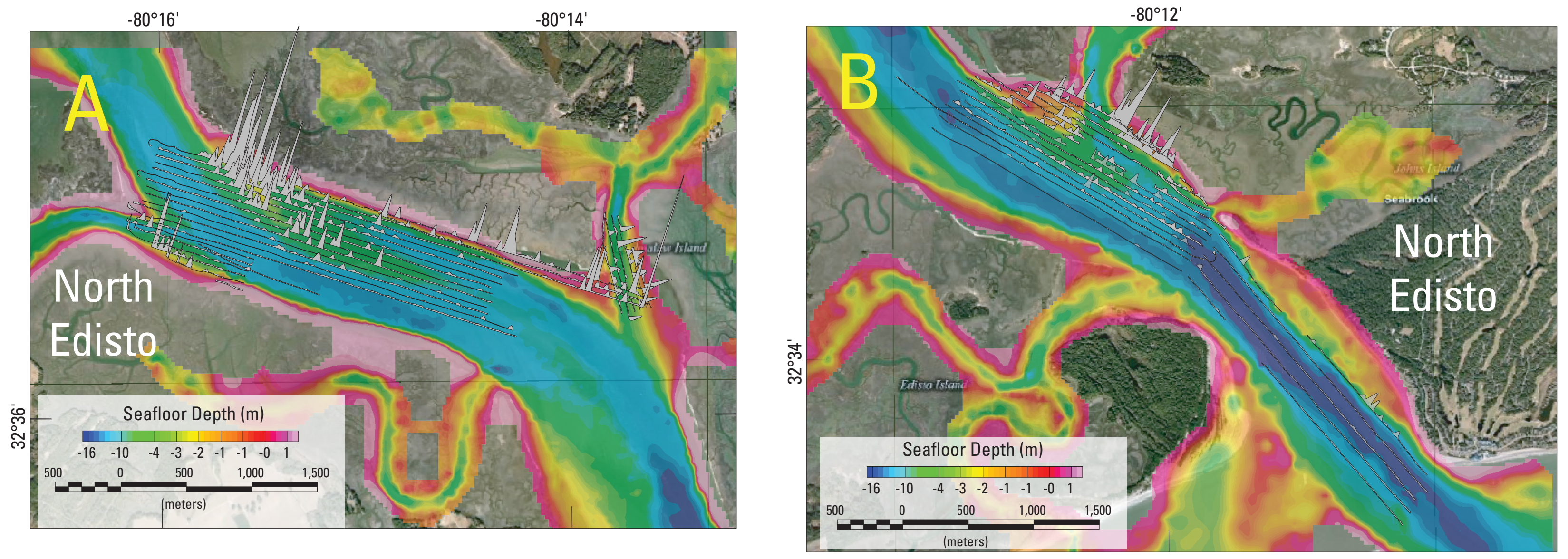
Shipboard sidescan sonar and magnetic surveys were conducted in tidal rivers and inlets near Charleston, S.C. Yellow lines (section 4) delineate ship tracks in areas A, B, and C. Filled circles (section 4, far left) denote stream sediment samples (see section 2).

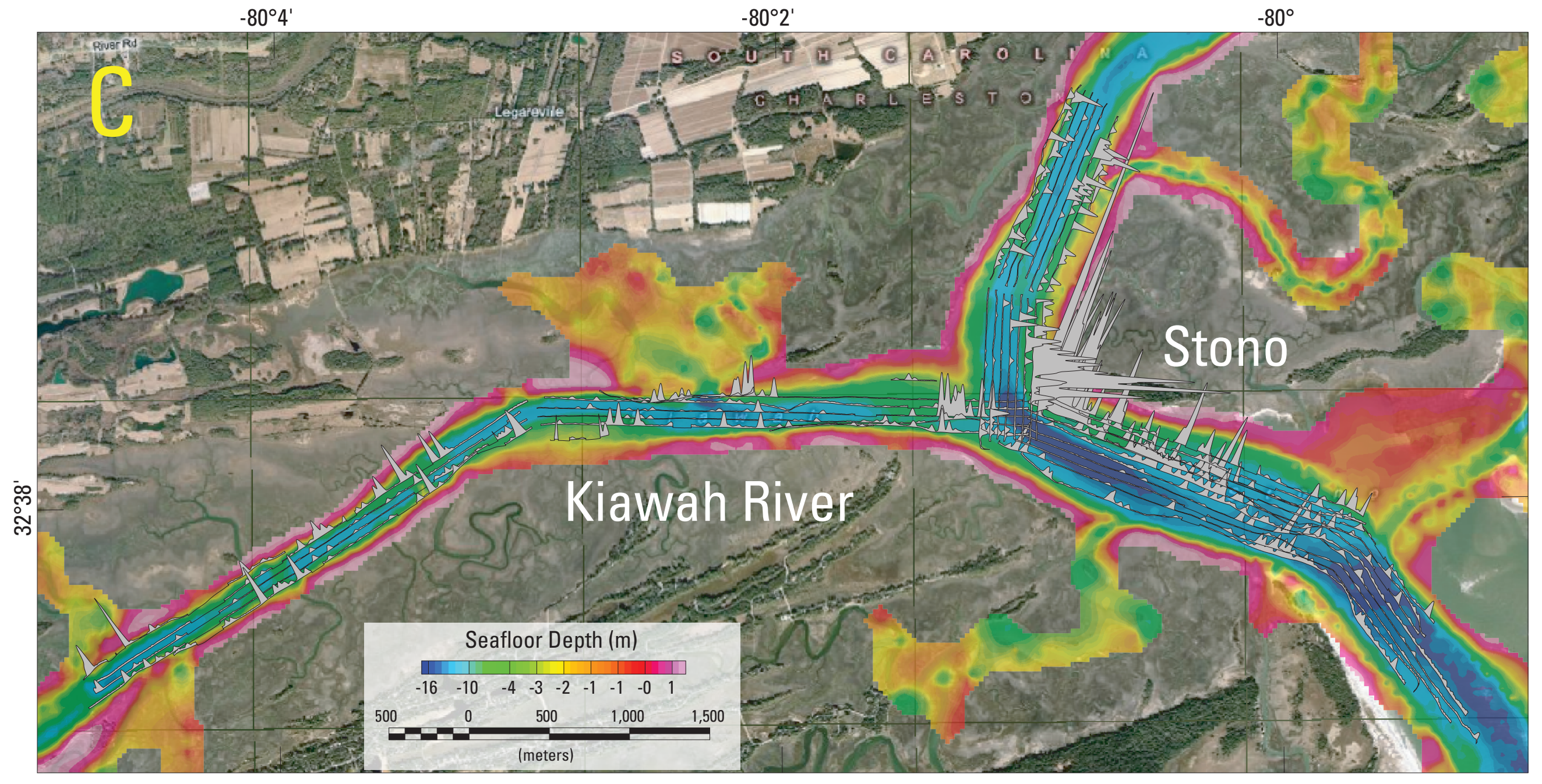
Short-wavelength magnetic anomalies can be highlighted using spectral filtering (see section 8). Peaks in short-wavelength spectral amplitudes, shown as gray-filled profiles in section 5, represent concentrations of shallow magnetic sources. Anthropogenic sources typically produce single isolated anomalies, which are often associated with objects that can be seen in the sidescan data.

Clusters of short-wavelength magnetic anomalies are concentrated in shallow areas usually at river bends where there is confluence of waters that originate upland. Sediments with stronger magnetic properties are usually composed of Fe- and Ti-rich minerals that are denser than their silicon (Si)- and calcium (Ca)-rich counterparts and can thus become concentrated through sorting, forming what are essentially small placer deposits. The insides of river bends often represent depositional environments, but placer formation usually involves entrainment sorting, where lighter or less dense sediments are transported elsewhere. The presence of anomalies near the insides of river bends suggests that these areas may undergo a balance between deposition and entrainment that works to concentrate heavy minerals.

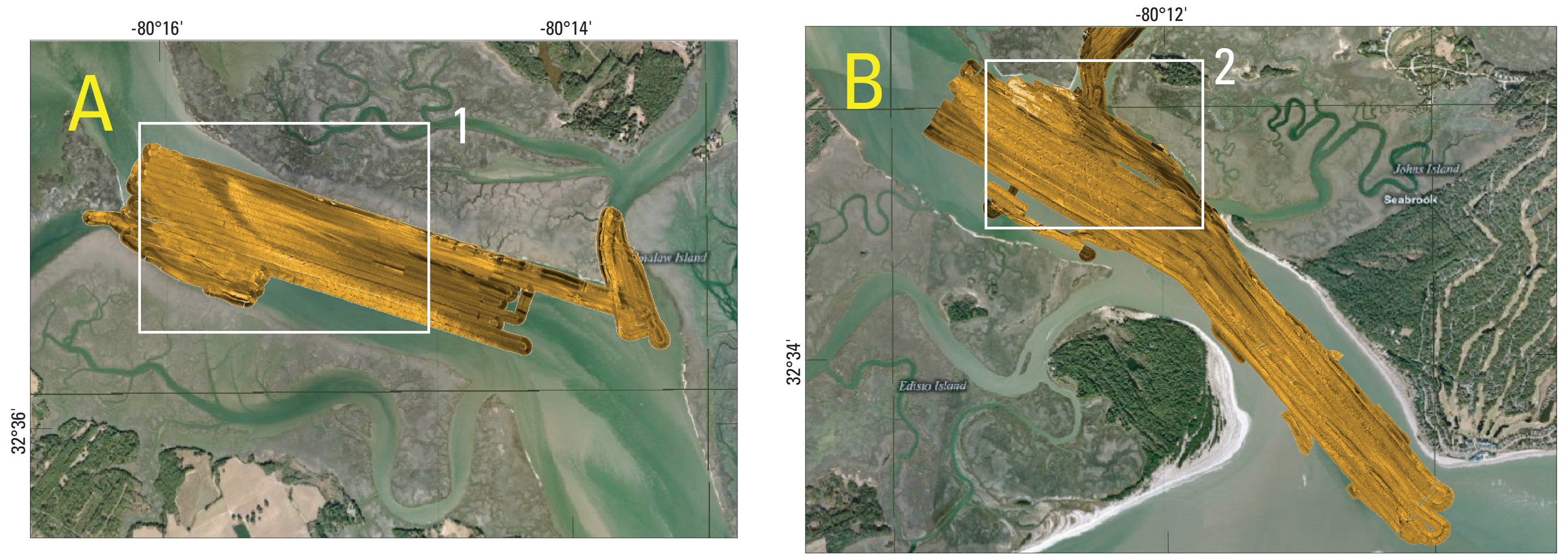
The Kiawah River exhibits very few grouped magnetic anomalies. It is much younger than the Stono and North Edisto inlets, aligned coast-parallel and bounded on either side by oyster reefs. The Kiawah River is thus likely to receive a much lower concentration of Fe- and Ti-rich sediments from upland sources.

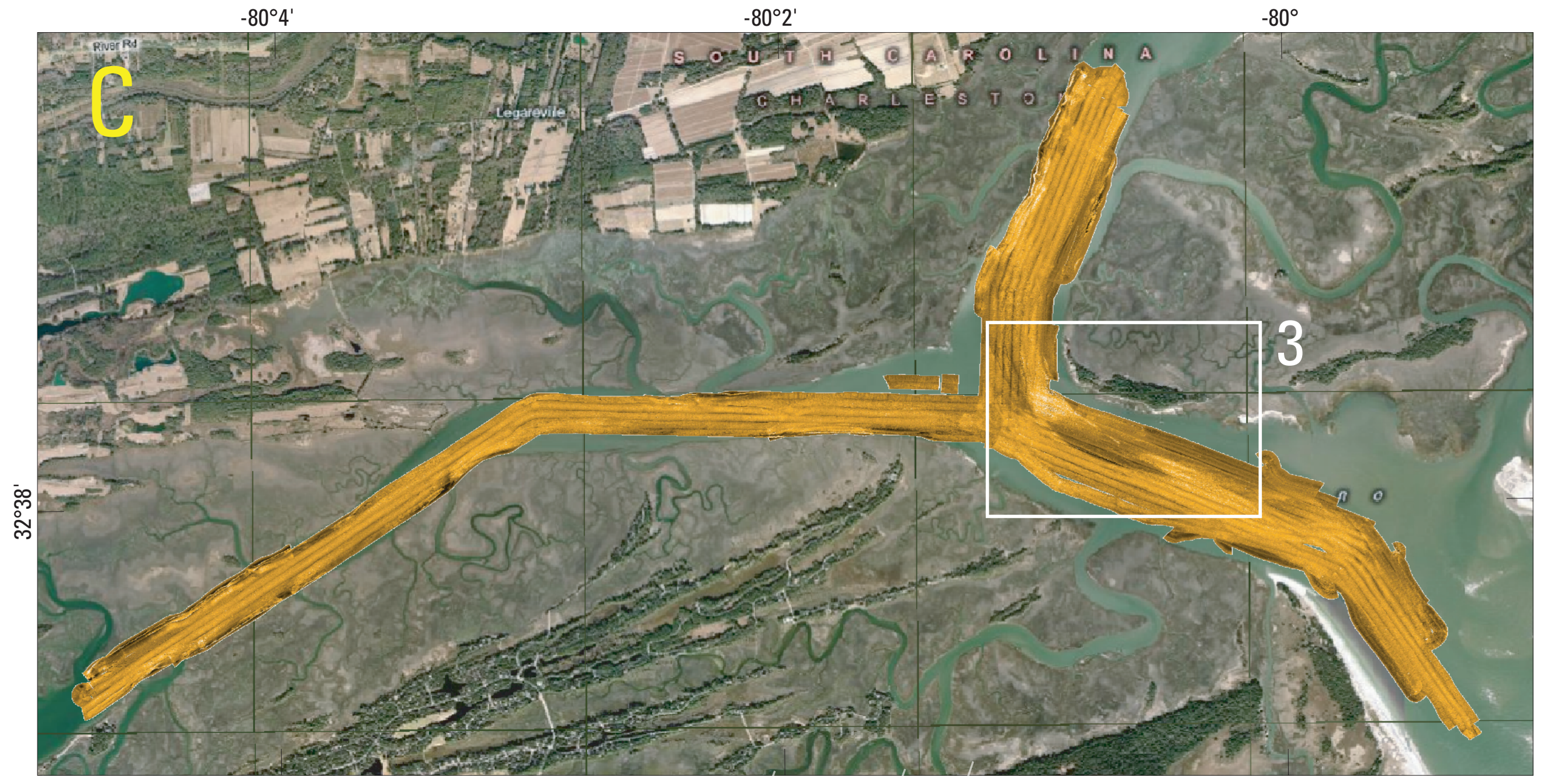
5. Magnetics—short-wavelength spectral amplitudes over seafloor depth





6. Sidescan sonar—900 kHz

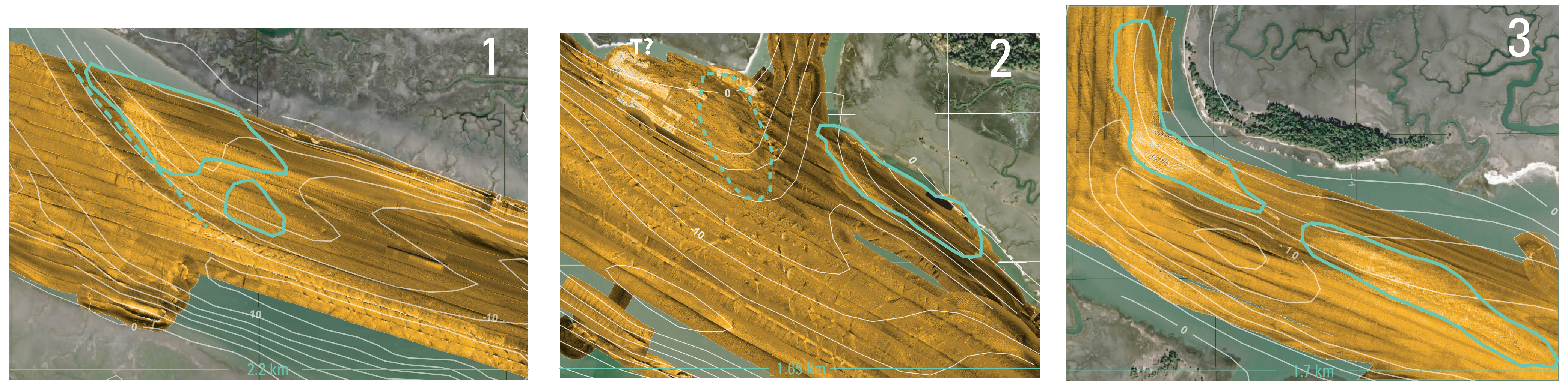




7. Anomalies and sediment type

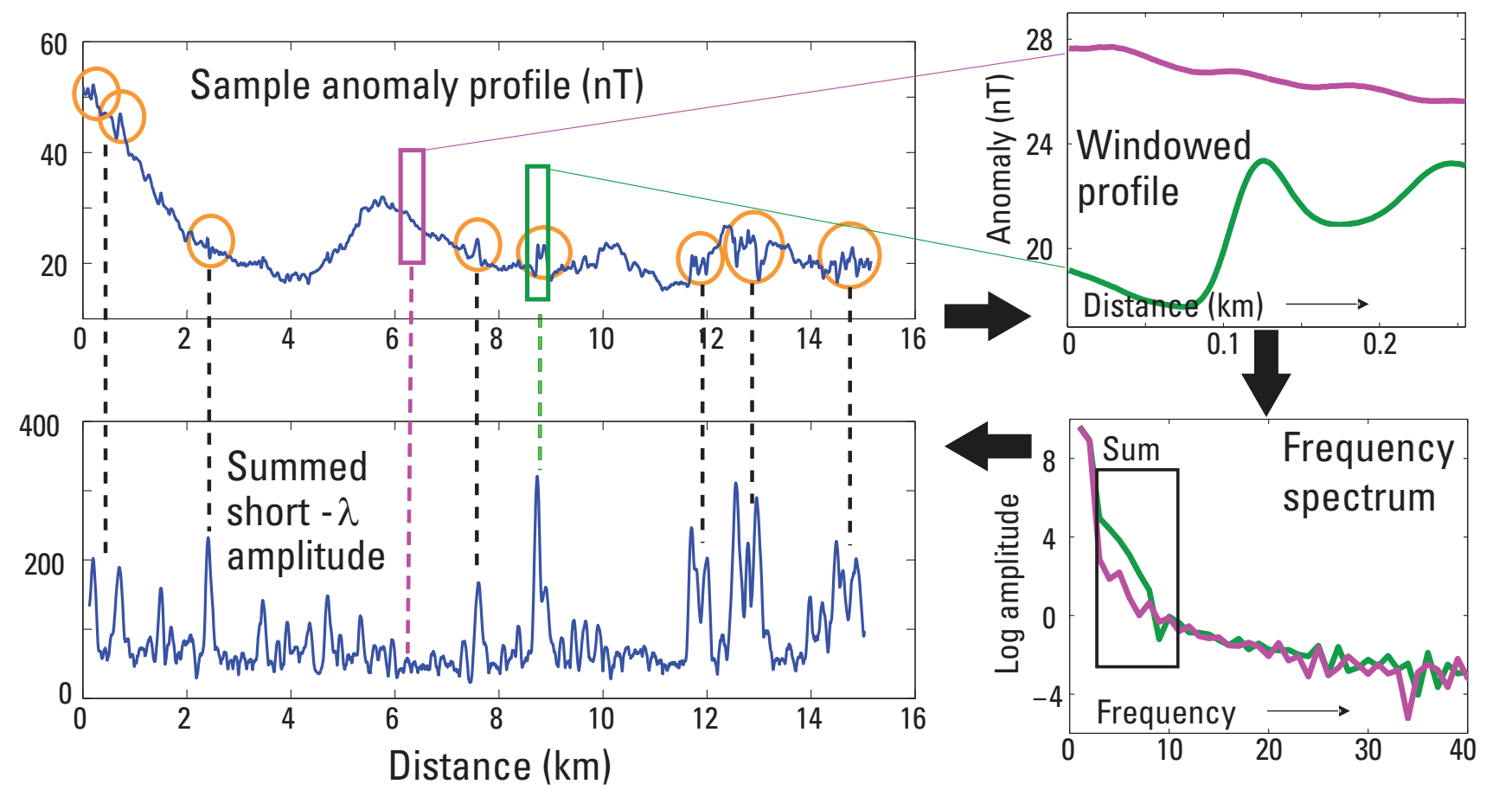
The sidescan sonar data, when ground-truthed using grab samples from Area A, show dark (less reflective; lower acoustic backscatter) areas associated with finer-grained sediments; lighter (more reflective; higher acoustic backscatter), smooth areas associated with medium- to coarse-grained sands; and hatched areas in the deeper channels that are associated with very coarse sands and gravels. The hatches delineate ripples created by stronger tidal currents, and the direction of these ripples varies since some areas were surveyed at different points in the tidal cycle.

Short-wavelength magnetic anomaly clusters, outlined in green (right), are mostly observed in areas representing medium- to coarse-sands. Exceptions include anomalies observed over some finer-grained sands and an absence of anomalies over possible Tertiary outcrop (panel 2, labeled "T"). White lines represent 2-m depth contours. Locations of these data are shown in section 6.



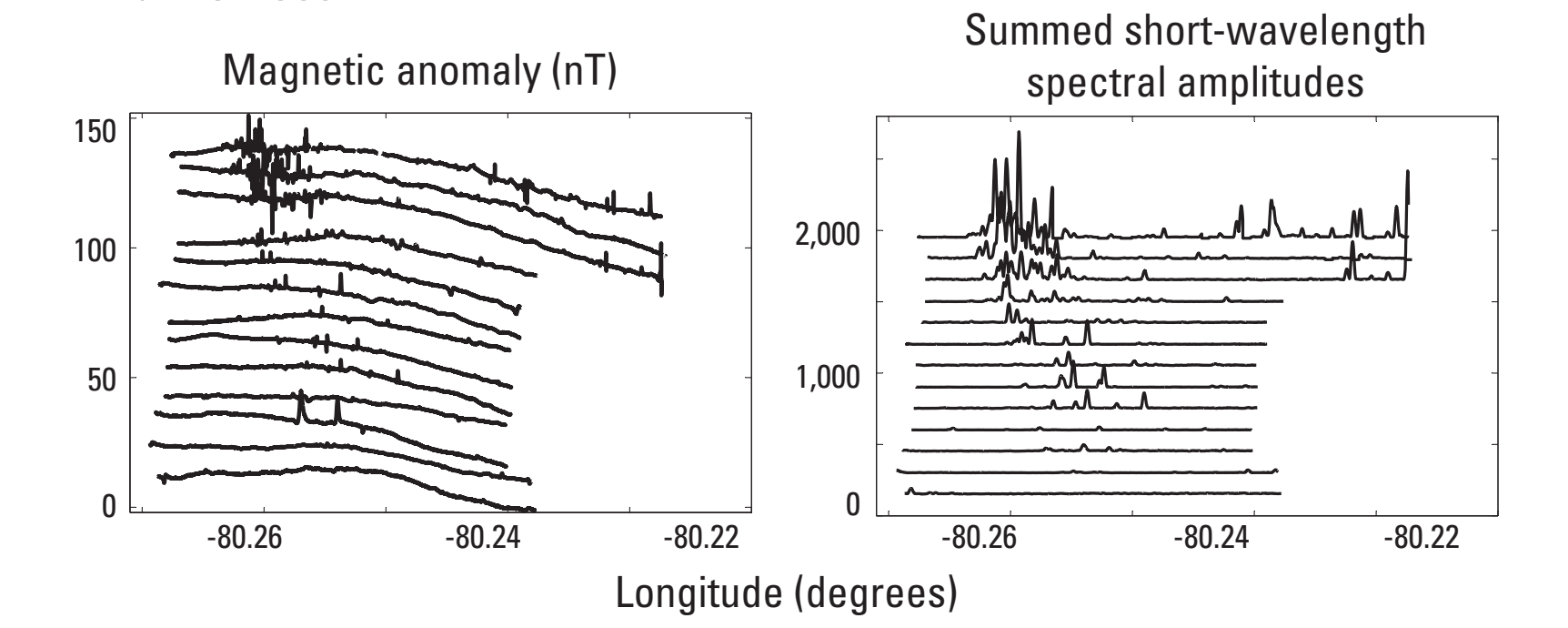
8. Magnetic filtering via spectral amplitudes

Anomalies associated with shallow magnetic sources can be visualized by applying spectral filtering methods to individual shiptrack profiles. These methods highlight areas where short-wavelength or "narrow" anomalies, which represent shallow magnetic sources, are present regardless of longer wavelength features. The approach is described in detail by Shah and others (2012). Briefly, for each point along a ship track, the profile is windowed around that point and the frequency spectrum calculated for the corresponding sub-segment (windowing helps to prevent "leaking" from longer wavelength anomalies). Amplitudes corresponding to shorter wavelengths are then summed and the value assigned to that point. This sum is highest where short-wavelength anomalies are present.



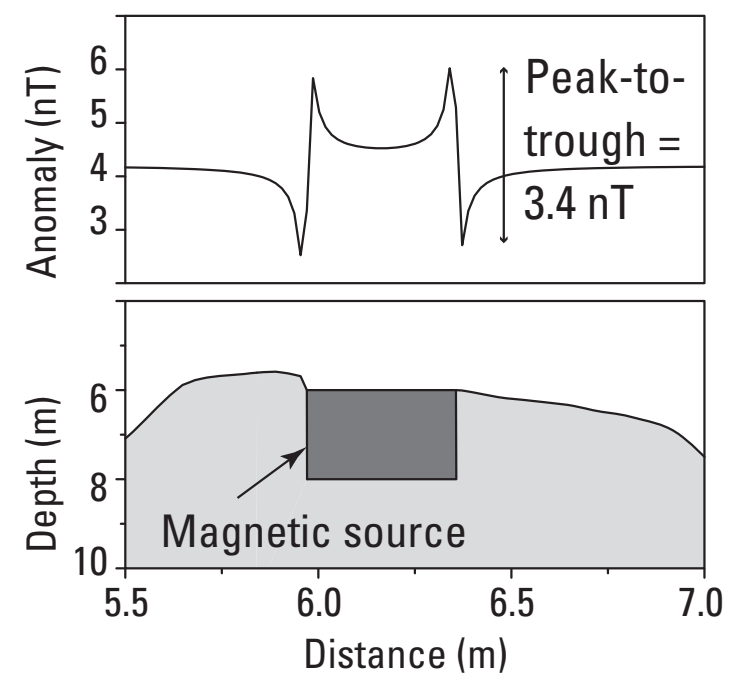
Example from the North Edisto River (Area A)

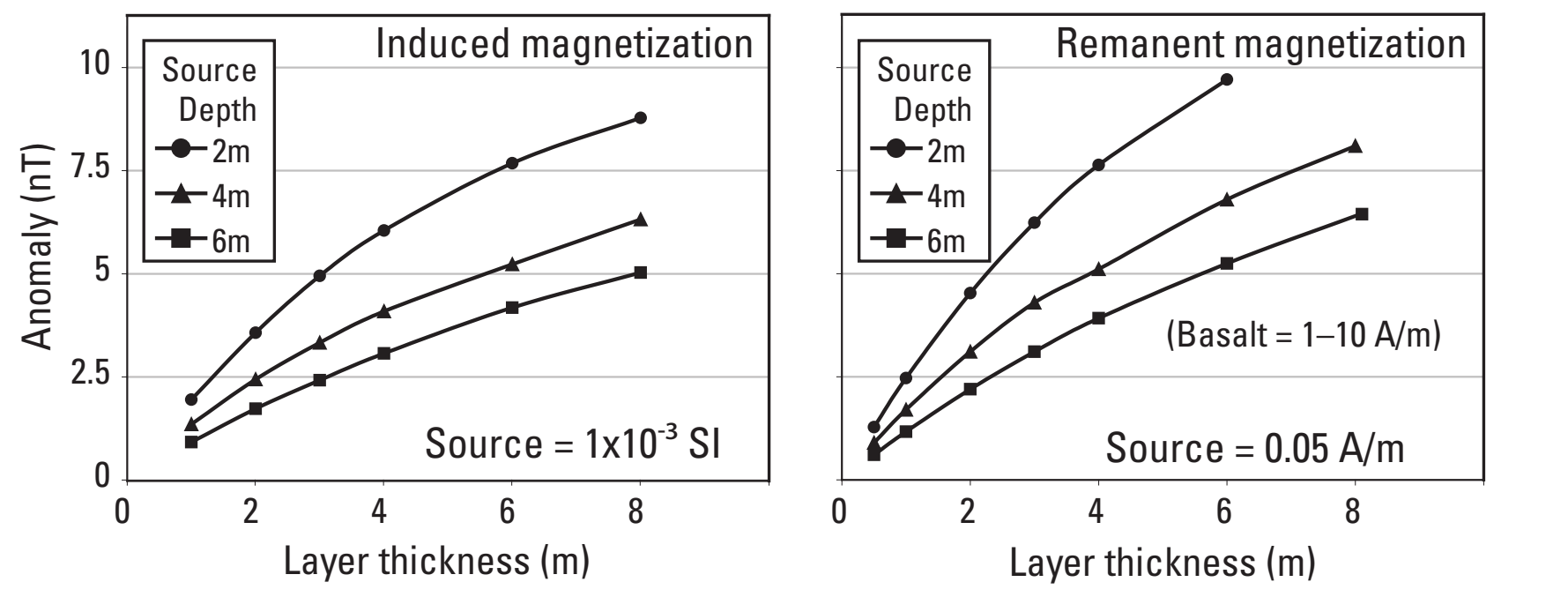
For this study, filtering parameters were set to highlight variations of about 14-m width or less.



9. Models

Models can be used to estimate the thickness of magnetic source layers. If magnetic grains are not aligned, induced magnetization will cause a canonical 3-m thick layer to generate a 5 nT anomaly for source properties listed. Slight alignment of magnetic grains (presumably in the direction of Earth's field) generates remanent magnetization, potentially reducing the needed layer thickness to about 1 m.





Notes: Models assume Earth's local field: amplitude = 48898.5 nT, declination = –7°, inclination = +61.5°. Source properties are based on sand samples from Chesapeake Bay (Shah and others, 2012).

10. References

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