FLUXGATE MAGNETOMETRY

AGAP

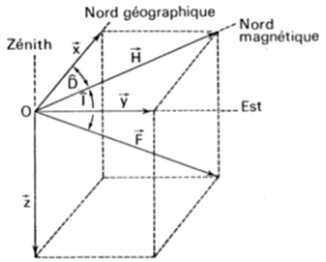
Method principle

Fluxgate magnetometry measures the vector component(s) of the Earth's magnetic field. Depending on the devices and applications, one or more components can be measured (vertical component at least). The unit is the nT/m.

This method is non-destructive and is called "passive" because it emits no waves and measures variations in the magnetic field generated by a buried ferrous metal object (pure iron or alloys containing iron).

The results obtained are used to establish:

- a 2D (X,Y) mapping for devices implemented from the surface
- a depth section for measurements made inside boreholes.



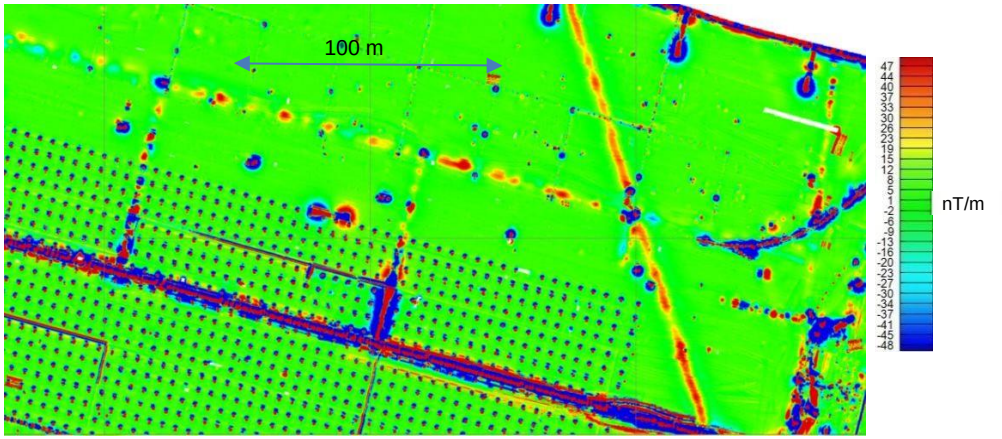
The Earth's magnetic field is defined by the vector F
The components of the magnetic field are determined by its inclination I (angle that the Earth's magnetic field makes with the horizontal), its declination D (angle between the geographic and magnetic North poles), its vertical component Z (vertical measurement point) and its horizontal components X (south-north) and Y (west-east)

Applications

- Type of treated problem:
  The analysis of the magnetic signatures generated by buried metallic objects makes it possible to characterize the object (size, mass, volume, depth, etc.) and to determine its position (X, Y).
- Common areas of use:
  - environment and civil engineering: Point or massive location of ferrous metal objects (tanks, drums, pipes, UXO, waste landfill area, etc.)
  - archaeology: searching for ferromagnetic objects, locating ancient remains.
- Detection capability: it depends on:
  - the spacing between the 2 coils in the probe ;
  - the geometry, magnetization and depth of the anomaly to be detected ;
  - the amount of ferromagnetic objects in the ground ;
  - etc.
- Resolution:

The resolution depends on the spacing between the sensors, the sampling frequency (usually 10 Hz or more) along the profiles and the density of buried metal objects.

The spatial resolution and accuracy of the measurements range is about cm (in X and Y) if the devices are coupled with D-GPS positioning.



Mapping obtained with 8-probe multi-detector 120 LW Ebinger/ MonX Sensys diagnostic pyrotechnique

Limitations/Constraints/Prohibitions

The properties of magnetism induce a plurality of signatures for the same object.

Detection is very difficult, if not impossible, if the desired targets are near, or above:

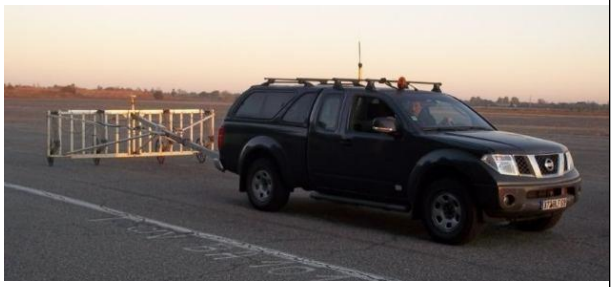
- surface metal elements (waste area…);
- backfill (clinker, metal waste) ;
- metal superstructure and infrastructure (fence, reinforced concrete slab, reinforcement, pipe, high voltage line …) ;
- highly mineralized terrains.

The operator must separate from all elements that may create magnetic disturbances during detection: mobile phone, belt, etc. The ground must be sufficiently clear (brushing and surface cleaning) to allow the passage of the operator and the detection device.

Example of right-of-way not suitable for the implementation of fluxgate magnetometry

Means necessary for the acquisition

- Equipement:
  The devices are composed of fluxgate magnetometric sensors, connecting cables, a data logger (scanning, visualization, data storage) or a control unit for single-sensor systems, a 12 V power supply, a non-magnetic frame for multi-detector mounting.
  For very precise measurements (cm), the use of a differential GPS is mandatory.
  Digital sensors do not require calibration. Analog sensors must be calibrated at manufacturers very regularly.
- Vehicle:
  The material can be transported by light transport (utility). For large cleared areas, devices can be towed by motorized means (quad, SSV (Side by Side Vehicle), 4x4).
  However, it is necessary to provide a sufficient length of drawbar to avoid the saturation effects induced by the vehicle (4 m for a quad and 6 m for a 4x4).
  Airborne measurements are not suitable for all problems.
- Staff and skills:
  1 qualified operator for the implementation, 1 qualified geophysicist for the interpretation, 1 not qualified assistance to help with the installation of the devices, the preparation of the field and the ground marking if necessary.



Example of different types of fluxgate devices: 4 VALLON georeferenced sensors (top left), Foerster monoprobe (top right), 8 EBINGER/SENSYS georeferenced sensors towed by a vehicle (bottom)

Field Implementation

- Preparatory work:
  - administrative declarations, property work authorizations, parking area evacuation (customer responsibility) ;
  - pruning and brushing required in a dense plant environment ;
  - removal of surface visible ferrous metal elements ;
  - accurate topographical survey of boundaries and site singularities that may affect the quality and understanding of measurements and interpretation ;
  - positioning of at least 3 landmarks (survey nails…).
- Measuring device:
  The spacing between the sensors and the profiles depends on the type of object sought (massive or linear point).
- Area grid:
  For a better coverage, profiles will be implemented in parallel and regularly.
- Detector mounting:
  The mounting time can vary from a few minutes for the single sensor detector, to more than 1/2 day for the mounting of a multi-detector tractable by a vehicle.
- Detector Compensation:
  The sensors are checked above a place with no anomalies due to buried metal targets. Depending on the equipment, this control is automatic or manual. The checks are made in the same place each time the device is restarted.

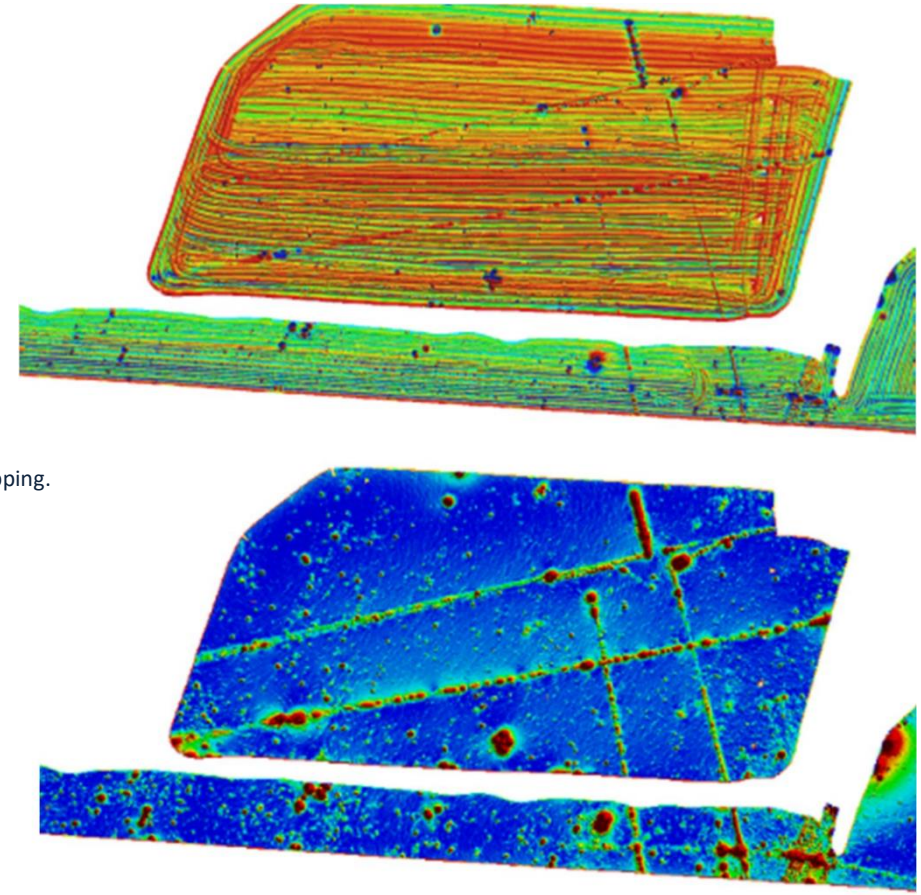
Example of mounting an 8 probes frame

- Device implementation:
  Regular speed must be maintained (especially for non-georeferenced devices), along previously materialized profiles. Setting up visual markers (cones, topofil, rope,…) ensures a precise passage in accordance with the planned survey, and avoids unexamined areas.
- Security:
  Prior visual recognition is carried out before any intervention to materialize and secure any danger zones.
  Depending on the concomitance of the intervention with other actors and the risks inherent in the diagnosed survey area, a PPSPS, or a prevention plan or a Safety Study can be drafted upstream.
  The implementation of these devices can be done with traditional mandatory personal protective equipment (helmet, orange vest, long sleeve jacket, trousers, goggles and hearing protection if necessary) except safety footwear which must be non-magnetic for any manual traction.
- Measurement quality control:
  Data are regularly transferred from the equipment.
  The acquired data is superimposed on the georeferenced plane background to verify the coverage rate and the correct positioning of the measurements.
- Production:
  Acquisition rate depends on the difficulty of moving on the ground (slopes, obstacles, condition of the ground) and the importance of the deployed team.
  On an easily accessible area, and depending on the devices used, the production can range from 0.5 to several hectares per day.

4 manually carried georeferenced probes mounting

Data processing and interpretation

- Achievement of a post-acquisition diurnal correction, if necessary ;
- Data filtering (non-linear filters, smoothing, etc.) ;
- Positioning drift corrections ;
- Assembly of geo-referenced magnetometry mapping ;
- Data interpretation :
    - dipole inversion ;
    - analytical signal calculation and resolution of the Euler line ;
- *Notes: these 2 methodologies are the most common for companies. This list is not exhaustive. Other methods of interpretation are possible.*
- Pointing of the most suspicious targets according to the parameters calculated by the interpretation methods (mass, size, volume, magnetization, etc.);
- Report on cartographic documents of surface obstacles found in the field, as well as all identifiable elements (networks, foundations...) ;
- Identification of notable surfaces that can hide the signature of deeper objects.
- Production: 1/2 day of processing per 1 day of acquisition, excluding report writing and mapping.



Example of the different data processing steps: Raw result (top) and analytical signal (bottom)

Results and Deliverables

- Study Report:
  The study report has several sections. An AGAP document specifying the layout of a standard report can be found on the website (www.agapqualite.org).
  - General Section : covers study generalities such as location, local geological context, objectives, procedures, equipment, interpretation methodology, etc. ;
  - Specific section: deals with equipment configuration, project team, detailed location and topography, field observations and measurement quality ;
  - Summary section: according to the objectives of the study, the expectations of the client and the terms of the contract, an advanced interpretation can be conducted. Conclusions and recommendations (on measures and possibly further work) are needed;
  - The report consists of a text volume and a cartographic volume, on paper and/or in electronic format. Map rendering is available in CAD and/or GIS format. Field data and topographic surveys are provided in ASCII format.

The interpretations will be presented by the following maps:

- mapping of survey zoning ;
- maps of the made profiles ;
- maps of raw magnetometric results ;
- maps of processed magnetometric results ;
- maps of notable features (saturated areas, networks, etc.) ;
- maps of selected magnetic signatures ;
- Table of selected anomalies: X, Y coordinates and estimated parameters. The estimated parameters vary depending on the used softwares and include: depth and/or mass and/or magnetization…

Example of map of interpreted results

Contractor/service provider dialogue

- At the client's expense:
  - detailed specifications with clear objectives and details on the nature of the project ;
  - plans and documents relating to the work, and the area to be explored ;
  - information about site access, security, and administrative permissions ;
  - documents relating to any previous investigations.
- At the expense of the service provider :
  - explicit proposal : justification of the proposed method, adaptation to the objective, description of benefits and limitations, influencing and/or uncontrollable factors, accuracy of measurements and realistic final results ;
  - professional quality study report : Review of objectives, applied methodologies, discussion of results, conclusions and practical recommendations.

For further information

- **2002**, Millon R., *les cahiers de l'AGAP - Magnétisme et prospection magnétique*
- **1995,** Blakely R.J. - *Potential Theory in gravity and magnetic applications*
- **2011,** Milsom, J., 2011*, Field Geophysics - Third Edition, WILEY, 304 p*
- **1997,** *Parasnis, D.S., 1997, Principles of Applied Geophysics - Fifth Edition, Chapman and Hall, 456 p*

Links

www.abemfrance.eu, www.bartington.com, www.ebinger.org, www.foerstergroup.fr, www.geometrics.com, www.vallon.us