Extensions to the DIGGS XML Transfer Standard for Data Directly Acquired from Geophysical Surveys

Report submitted to the Geo-Industry Geophysics Users Group

by

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Abstract
The ASCE GI Technical Coordination Council approved a Special Project to extend the Phase 1 DIGGS Geophysics work (Ponti and others, 2023), which initially focused on transferring processed geophysical field survey data, to now include transfer of raw field data prior to processing. This project has four key objectives: 1) provide an XML container for transferring data files directly generated from field geophysical surveys; 2) capture general metadata about field surveys (e.g. date/time, survey purpose, personnel and equipment); 3) describe survey locations using GML-derived objects to enable visualization; and 4) document receiver and source locations with their recording and source parameters. The proposed schema extensions introduce a new measurement feature object with component objects, along with three new sampling feature objects. These objects are defined in the Geophysics.xsd schema file at https://diggsml.org/schemas/2.6/Geophysics.xsd and are fully documented at https://diggsml.org/docs/2.6.

The schema extensions are designed to accommodate storage and transfer of virtually any type of raw field data, as well as the final processed results. Now in beta testing, these extensions should significantly enhance data exchange and interoperability across geologic, geotechnical engineering, and geophysical communities to support comprehensive geo-engineering activities including analysis, design, planning, construction, visualization, and archiving.

Introduction
Prior to initiation of the DIGGS extensions for geophysics in 2022, DIGGS schema development had focused on capturing and transferring directly measured physical property data from ground investigations. These investigations typically included laboratory tests on field samples, in-situ tests, and monitoring activities that directly measure physical properties in the earth or track their variation over time.

Geophysical survey data presents unique challenges compared to other measurements previously handled in DIGGS. The key distinction is that geophysical methods often measure parameters that differ from the derived physical properties of interest. Additionally, the spatial distribution of the derived properties may occupy a different domain than the original observations. For example, a seismic refraction survey uses an array of sensors to measure wave-amplitude time series at points along a linear transect, which after processing yields estimates of seismic velocity distributed across a vertical cross-section.

The Phase 1 DIGGS task group decided to prioritize developing schema objects for processed geophysical data for several strategic reasons:

- For design purposes, practitioners primarily use processed results, making this capability immediately beneficial.
- Processed results from nearly any geophysical method can be transferred with minimal schema alterations.
- Processed data results are relatively less voluminous than data produced during acquisition and can be transferred efficiently and directly in XML using compact encoding techniques.

The Phase 1 effort resulted in creating a specialized ProcessedGeophysicalResult procedure object to describe the processing steps that generate final results from field data. Several sampling feature and geometry objects were also developed to accommodate processed geophysical results occurring within 2D (e.g., cross-sectional or map areas) and 3D (volume) domains. These objects support the storage and transfer of virtually any processed geophysical data within spatial domains. Additionally, with the definition of compound coordinate reference systems that include a temporal axis, the schema supports processed data within spatial-temporal domains (such as seismic time sections and time volumes).

The primary goal of the Phase 2 Geophysics effort is to develop schema objects that support the transfer of 'raw data' acquired during data acquisition, which serves as input to the processed results. As with Phase 1, the task group was led by Daniel Ponti and Caleb Kaminski, with significant contributions from task group participants (Table 1), who provided guidance, domain expertise, and sample datasets."

Table 1. List of DIGGS Geophysics task group participants

Daniel Ponti, (USGS Retired) and Caleb Kaminski (Michigan Tech University), Technical Leads
Elizabeth Baranyi, Seequent
Roy Bowling, Collier Consulting, Inc.
Allen Cadden, Schnabel Engineering, Inc.
Ross Cutts, Geosetta
Derrick Diesenbrock, U.S. Federal Highways Administration
Lorraine Godwin, Seequent
Jeff Reid, Hager-Richter Geoscience
Phil Sirles, Collier Consulting, Inc.
Kolby Pedrie, Geometrics

The task group decided not to attempt to develop a standard XML format for the transfer of raw field measurements. Currently, these data vary widely in format depending on the geophysical technique and vendor, and many such files are quite large and are stored in proprietary binary formats tied to specific hardware and software. Clients who may want to examine or reprocess the field data likely have the expertise and the software to work with these files directly, thus there is little benefit to standardization of the raw data. Instead, the Phase 2 DIGGS extensions are designed to standardize the reporting of field survey metadata (e.g. survey location, source, and receiver positions, recording and source parameters) and to provide an XML container for the transfer of the original field survey data package. In this way, DIGGS provides a standard format for visualizing the field survey geometry and for evaluating the efficacy of the field survey and the processed results, while also providing a means of transferring raw field data in its original format for further processing if desired.

Proposed DIGGS Schema Extensions

New SamplingFeature Objects

Geophysical field survey measurements occur along linear transects (arrays, transects, boreholes) or are distributed across an areal extent. These sampling spaces define the geometric domain of the survey data collection. Figure 1 illustrates the three new sampling features developed to complement the existing Borehole and similar SamplingFeature objects in DIGGS:

1. GP_Trackline: A single linear feature lying on the earth's surface (Figure 1A). This object derives from AbstractLinearSamplingFeature and defines its geometry through a reference point (typically at one end of the track) and a centerline property represented by a LinearExtent object. The coordinates of both the reference point and centerline can use either 2D or 3D geographic or projected coordinate reference systems. Like the Borehole object, GP_Trackline supports linear referencing, allowing positions along the track (such as receiver or source locations) to be described by distance along the trackline. As shown in Figure 1A, GP_Trackline serves surveys that produce processed results for a vertical profile or cross-section, such as electrical resistivity tomography (ERT), seismic refraction or reflection studies, and GPR.

2. GP_MultiTrack: Used for surveys that collect data along two or more tracklines where the processed results utilize data from multiple tracklines to produce results within 2D areas or 3D volumes (Figure 1B). Examples include 3D seismic or aeromagnetic surveys, as illustrated in Harrison and others (2007). GP_MultiTrack derives from AbstractSamplingFeature and functions as a collection of individual GP_Trackline objects that comprise the overall survey.

3. GP_ArealSurvey: A 2D object deriving from AbstractPlanarSamplingFeature that models the survey area as a polygon (Figure 1C). This object bounds the area of geophysical surveys where data collection points are randomly located rather than aligned along tracklines, as demonstrated by the gravity survey example from Chavanidis and others (2022). The geometry is defined by a reference point (PointLocation), a feature extent (Polygon), and optionally a reference edge if the feature requires planar referencing. Like GP_Trackline, coordinates can use either 2D or 3D geographic or projected coordinate reference systems.

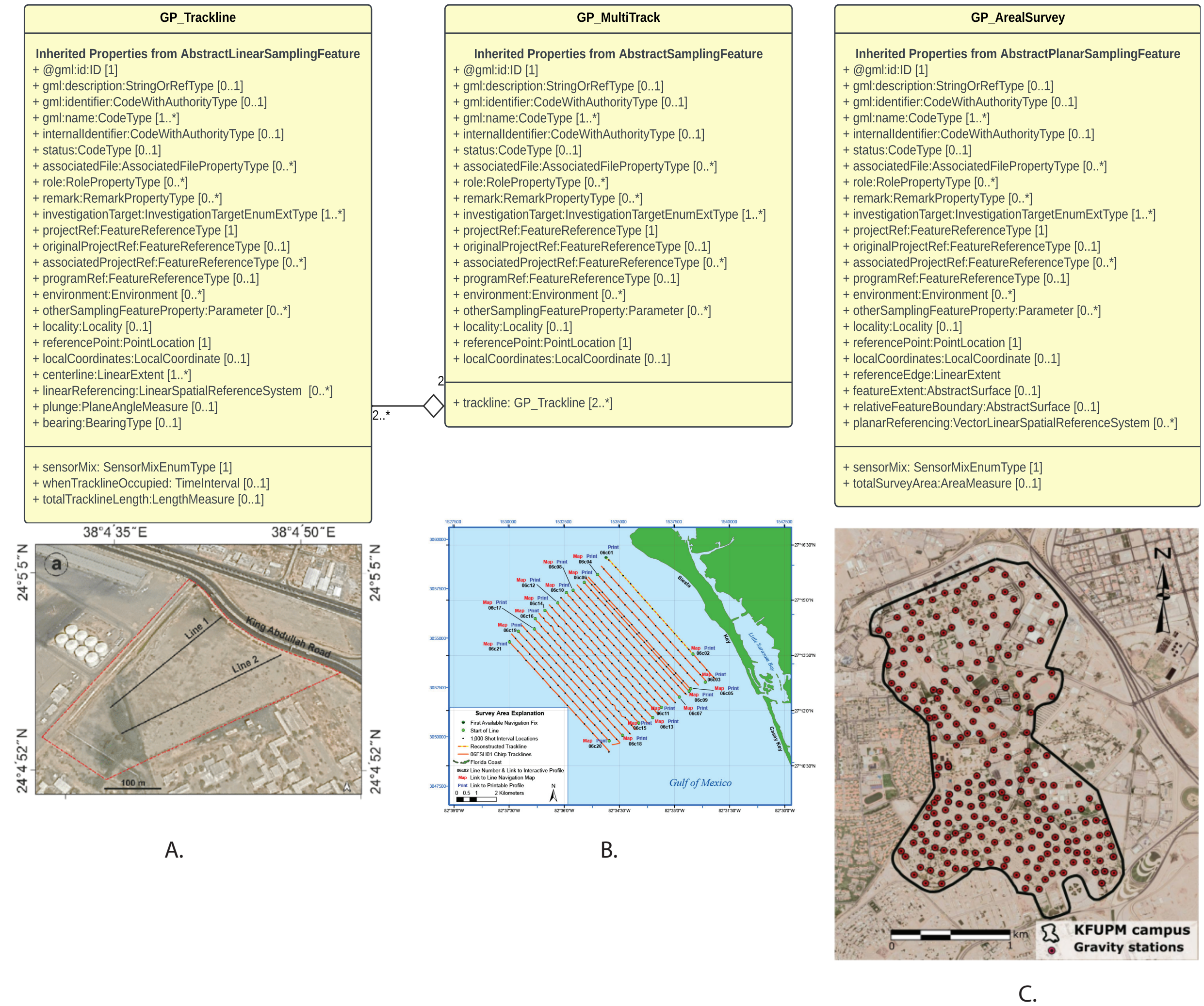

Figure 1. Generalized UML class diagrams of the new sampling feature objects for geophysics and real-world examples of these features. For clarity, several existing component objects are not shown. A. GP_Trackline Is used where the extent of a geophysical survey occurs along a single transect. In the image, Line 1 and Line 2 are each GP_Tracklines for two ERT studies (Dhamiry and Zouaghi, 2020). B. GP_MultiTrack is used where a geophysical survey utilizes measurements from two or more single tracklines, irregularly spaced or in a grid pattern, as is typical in 3D seismic surveys (Harrison and others, 2007). GP_MultiTrack is a sampling feature object that is collection of individual GP_Trackline objects. C. GP_ArealSurvey is a planar sampling feature (polygon) that encloses an area where field measurements are obtained and where measurements do not occur along a trackline or grid, as is typical for gravity surveys (Chavanidis and others, 2022).

GeophysicalFieldSurvey measurement object

GeophysicalFieldSurvey is a new measurement object proposed to hold both field survey data and associated metadata. As shown in Figure 2, this object derives from AbstractMeasurement and shares common properties with other measurement types. The UML class diagram in Figure 2 illustrates the inheritance structure and key properties, including:

- Basic identification and description fields (gml:id, gml:description, gml:identifier, gml:name)

- Survey metadata (personnel and roles)
- Optional pointer to the Test object containing processed results
- Timing information (samplingTime for field survey execution, resultTime for data availability)

The mandatory geophysicalMethod property identifies the specific geophysical approach from an enumerated list (Table 2).

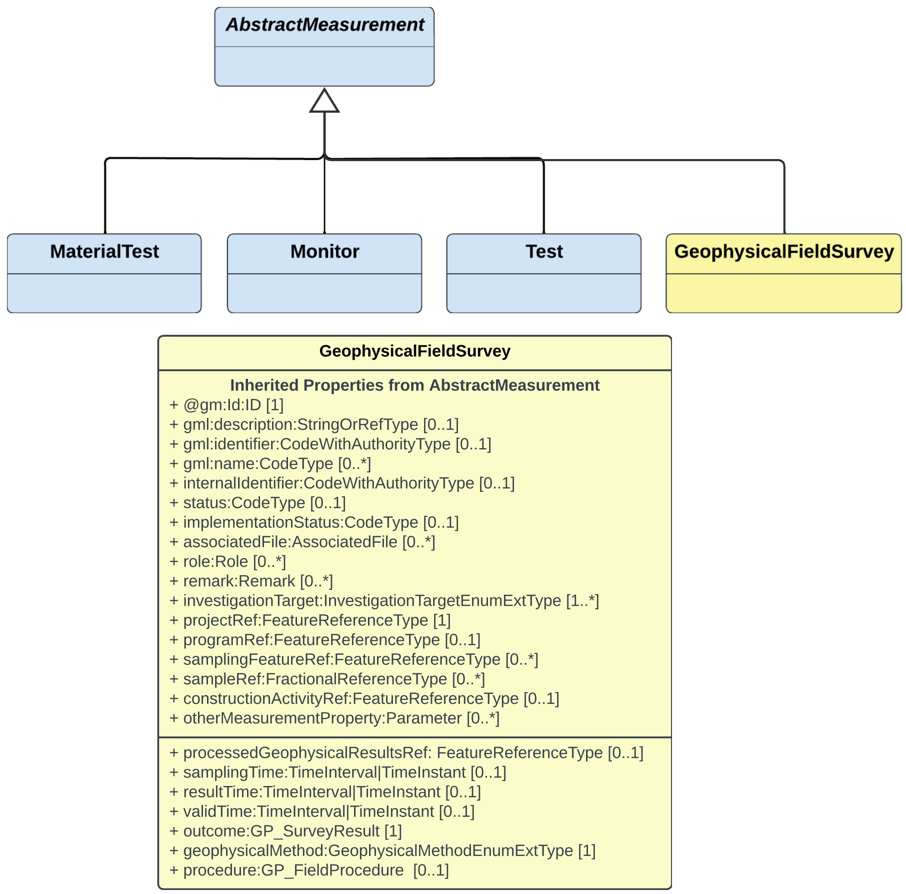

Figure 2. Generalized UML class diagram(s) showing the GeophysicalFieldSurvey measurement feature (top, yellow) in relation to existing measurement features (top, blue), and the feature's properties (bottom, yellow)

Table 2. List of Geophysical Field Methods Supported in DIGGS

borehole crosshole seismic	**marine seismic**
borehole image log	**microtremor array measurement (MAM)**
borehole seismic downhole source	**multichannel analysis of surface waves (MASW)**
borehole seismic surface source	**natural gamma radiation**
electrical resistivity tomography (ERT)	**neutron logging**
electromagnetic induction (EMI)	**passive seismic (HWSR)**
frequency domain reflectometry (FDR)	**refraction microtremor (ReMi)**
gamma-gamma density	**seismic reflection**
gamma ray spectrosopy	**seismic refraction**
gravity, absolute	**self-potential**
gravity, relative	**spectral analysis of surface waves (SASW)**
ground penetrating radar	**time-domain reflectometry (TDR)**
induced polarization	**transient electromagnetics (TEM)**
magnetic resonance sounding (MRS)	**vertical electrical sounding (VES)**
magnetometry,	**very low frequency method (VLF)**
magnetotelluric (MT)	

The bulk of survey information resides in two complex objects contained within the outcome and procedure properties:

1. **GP_SurveyResult** (Figure 3): Contains references to raw data files and provides source/receiver locations. The UML diagram shows how this object manages data packages and location information.

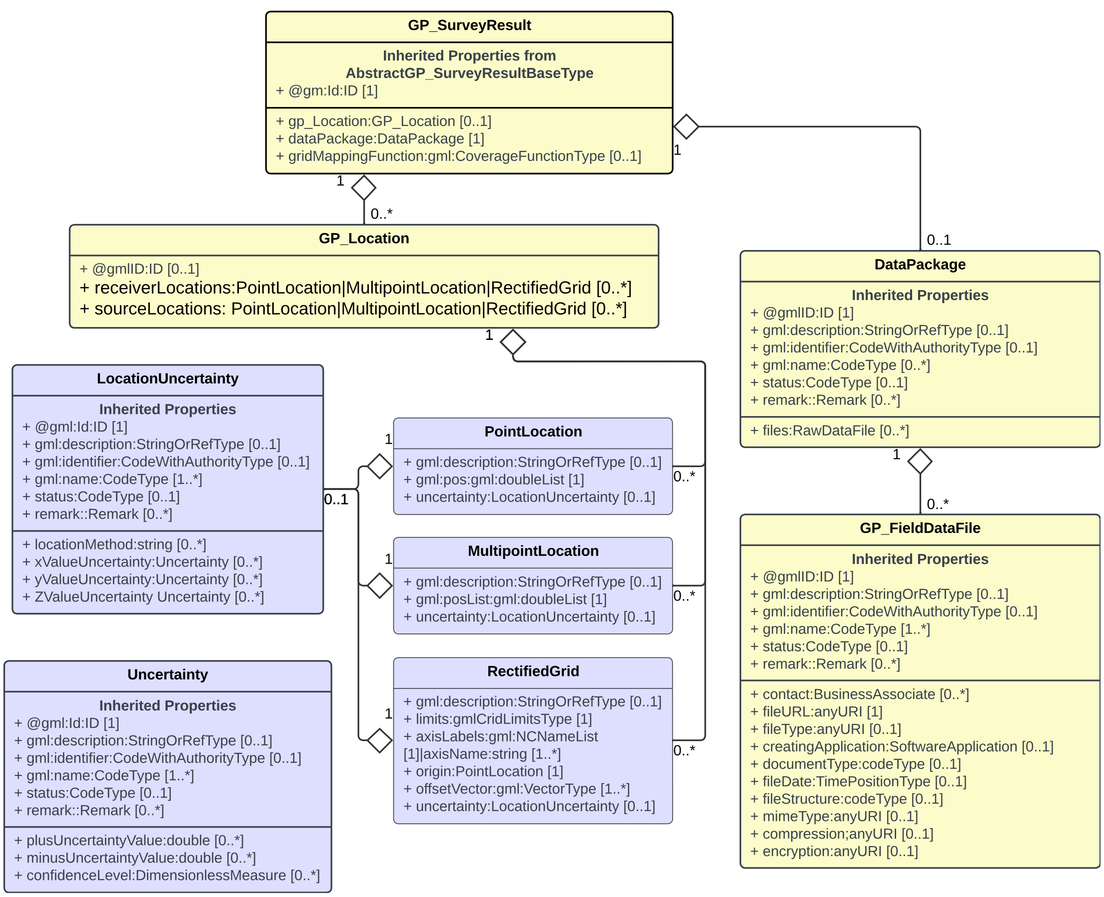

Figure 3. Generalized UML class diagram of the GP_SurveyResult object and its associated components. Yellow objects are those created for this proposed extension; purple objects are pre-existing within the DIGGS schema.

The gp_Location property holds a GP_Location object that optionally lists all the locations where sources were placed and where data were collected (receiver locations) for the survey. These locations are points and can be encoded as a PointLocation (for a single source or receiver location), MultiPointLocation (for multiple source and/or receiver locations) or as a RectifiedGrid (for multiple source and/or receiver locations that are regularly spaced). GP_Location provides a quick overview of the location and density of data collection points for the survey but does not associate locations to specific receivers or sources or specific source/receiver geometries. This information, if available, can be provided in the GP_FieldProcedure object.

2. **GP_FieldProcedure** (Figure 4): Holds detailed information about equipment configurations and survey parameters. As illustrated in the UML diagram, this object manages the complex relationships between equipment specifications, configurations, and measurement parameters.

GP_FieldProcedure carries information on three types of equipment: 1) receivers (the sensors and detectors that take measurements, e.g. GP_Receiver object), 2) sources (the devices that generate energy for active experiments, e.g. GP_Source object) and 3) data acquisition systems (the equipment that records the data from the receivers, e.g. GP_DataAcquisitionSystem object). All these equipment objects inherit from AbstractEquipment and derive from their own AbstractEquipment subtypes (e.g. AbstractGP_Receiver) so that additional specialized equipment objects can be easily added in the future.

GP_Source and GP_Receiver have similar properties; each contains type properties whose values describe the general type of source or receiver from an enumerated list (Table 3). GP_FieldProcedure can carry any number of GP_Receiver and GP_Source objects. In cases where a survey uses a large number of sources or receivers of the same make and model (e.g. an array of geophones used in a seismic survey), like pieces of equipment can be represented by a single GP_Source or GP_Receiver object by setting the value of the isGroup property to true and by setting the property's attribute value (noReceivers or noSources) to the number of like equipment used. GP_Receiver also has a detector property that can be used to describe the properties of individual detectors in complex receivers (e.g. 3-component seismometers), including the property being measured, measurement axis orientation, and recording space (e.g. frequency, temporal, or non-varying).

The equipment objects developed for geophysical surveys at this time are quite generic. Additional properties can be recorded using the otherEquipmentProperty property, but if needed for interoperability reasons, other more specialized equipment types can easily be developed in future versions of the schema.

Information about source-receiver geometries is handled by the configurations and platforms properties of GP_FieldProcedure and their contained Configuration and Platform objects.

Figure 4. Generalized UML class diagram of the GP_FieldProcedure object and its associated components. For clarity, several existing component objects are not shown.

Table 3. Receiver and Source Types

Receiver Types	SourceTypes
accelerometer	Impulsive
electrode	nonimpulsive
Geiger-Muller counter	
geophone	
gravimeter	
hydrophone	
magnetometer	
RF coil	
radio wave antenna	
scintillation detector	
seismometer	
sodium iodide detector	
VLF receiver antenna	

A Configuration is a geometric arrangement of discrete receiver locations or receiver and source locations (modeled as point geometries). A GP_FieldProcedure may have more than one configuration where a single configuration may not extend over the entire set of associated sampling features. For example, a seismic reflection survey may consist of one or more source-receiver arrays that are moved progressively along a GP_Trackline. In this case, each array location would be described by a Configuration object.

Configurations have two primary properties, receiverInfo and sourceInfo, which are property types that contain ReceiverInfo and SourceInfo objects, respectively. Both objects have similar properties. There are properties in both for recording general information about the configuration, such as number of receivers/sources, number of receiver/source stations (locations where receivers/sources are placed, receiver/source type and receiver/source spacing. Specific information on the geographic location of sources and receivers are provided in the sourceLocations and receiverLocations property types and their contained objects respectively. These objects contain a property to reference the samplingFeature (e.g. GP_Trackline, GP_ArealSurvey) upon which the sources/receivers are located, a reference to specific receiver/source equipment (receiverRef/sourceRef), and a locations property that contains PointLocation, MultiPointLocation or RectifiedGrid objects with the receiver/source coordinates.

A Platform is a geometric arrangement of receivers and optionally a source that that are in fixed position relative to each other, and where the entire geometric arrangement moves together along GP_Tracklines. Platforms are also used where a receiver or receiver configuration moves continuously and where measurements are taken at discrete time intervals. Examples of surveys that use platforms are GPR, magnetic surveys on moving platforms (aeromag), marine seismic experiments where a streamer is attached to the ship, and borehole velocity surveys such as dipole sonic and OYO suspension logs.

The Platform object functions similarly to the Configuration object. It contains properties describing the number of receivers/sources on the Platform, receiver and source-receiver spacing and receiver array and source-receiver array orientations relative to the direction of Platform travel. The platformMovement property type and its contained PlatformMovement object contains properties describing Platform velocity and sampling rate, and/or specific locations where the Platform has recorded data.

It’s important to note that all the components of GP_FieldProcedure are optional, as is the use of GP_FieldProcedure itself. This allows users the flexibility to provide as much or as little metadata about the field survey depending on the use case.

The proposed GeophysicalFieldSurvey measurement feature and its component objects, plus the new GP_Trackline, GP_MultiTrack and GP_ArealSurvey provide sufficient means to describe both simple and complex field survey activities and geometries, as well to transmit the “raw” field data within the context of the survey metadata. The following section will provide some implementation examples for different survey scenarios and use cases, including encoding examples of how specific source/receiver equipment objects are linked to their locations.

Implementation Examples

The proposed schema extensions provide the flexibility to describe the field survey and associated “raw” data in little or significant detail depending on the use case. The following examples provide a series of DIGGS XML snippets for several use cases.

Example 1 – Single track resistivity (ERT) survey

In this example we will consider a hypothetical electrical resistivity survey run along a single 500 m-long profile (Trackline-1, Figure 5A) with coordinates in UTM Zone 11N. The survey uses four sensors, two stainless steel current electrodes (sources C1 and C2, Figure 5A), and two stainless steel voltage electrodes (receivers P1 and P2, figure 5A). For this example, we won’t be considering the data logger used to record data from the above sensors as it does not factor into the survey geometry.

The sensors are located along Trackline-1. P1 and P2 are stationary throughout the survey and located 230 and 270 meters east of Trackline-1’s origin (reference point, see Figure 5A). In the initial configuration of the survey, the current electrodes C1 and C2 are placed 200 and 300 meters east of Trackline-1’s reference point (see Configuration 1, Figure 5A), and are subsequently moved apart by 50 m each along the trackline until the last measurements are taken when C1 and C2 are located at the trackline endpoints (Configurations 2 – 5, Figure 5A).

Data from the sensors are acquired using Geometrics EH5Pro software and the resultant.ts data files are zipped together into a file named Res1.zip and is in the same directory as the XML instance.

For this example, we will presume that the field data has been processed, and the tomographic results provided in a DIGGS Test object with gml:id="ProcessedERT" and included in the same XML instance as the field survey data.

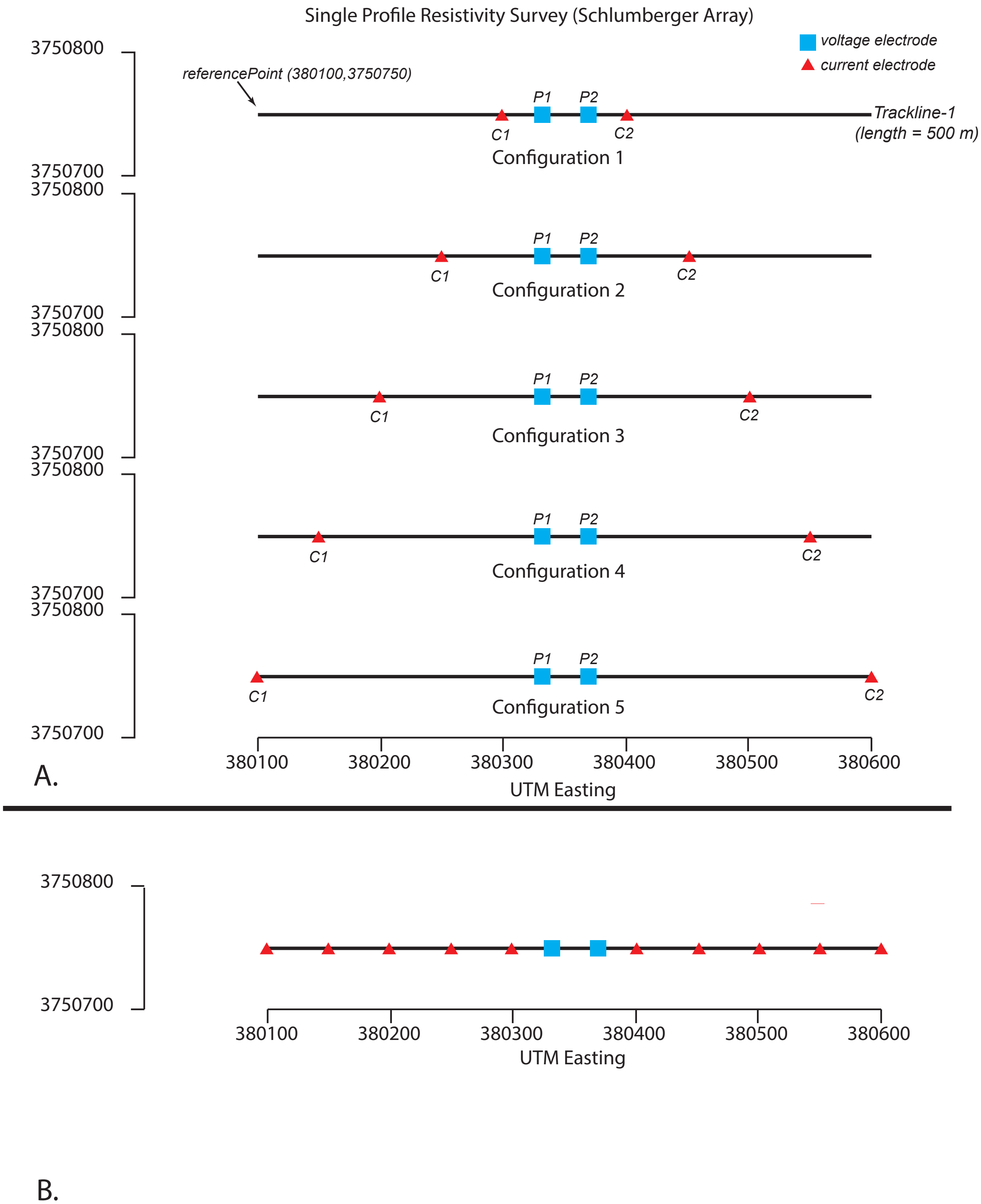

Figure 5. Example configurations. A. Resistivity survey along a single trackline. The survey utilizes two current electrodes (red triangles) as sources and two potential electrodes (blue squares) as receivers. The survey consists of five Configurations where the current electrodes are progressively moved away from the center. B. Visualization of information available to the end user about the field survey geometry from Scenario 3 below. Trackline and source and receiver locations are exposed but specific sensors are not identified, nor is the sequence of measurements as shown by the configurations in (A) above exposed.

Scenario 1: Transfer only field survey location

In this scenario, we need to create a GP_Trackline sampling feature that defines the geometry of the survey location:

```
<samplingFeature>
  <GP_Trackline gml:id="Trackline-1">
    <gml:name>Trackline 1</gml:name>
    <investigationTarget>Natural Ground</investigationTarget>
    <projectRef xlink:href="#proj1"/>
    <referencePoint>
      <PointLocation gml:id="Trackline1-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
        <gml:pos>380100 3750750</gml:pos>
      </PointLocation>
    </referencePoint>
    <centerLine>
      <LinearExtent gml:id="Trackline1-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
        <gml:posList>380100 3750750 380600 3760750</gml:posList>
      </LinearExtent>
    </centerLine>
    <linearReferencing>
      <LinearSpatialReferenceSystem gml:id="Trackline1-lsr">
        <gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS">DIGGS:Trackline1-lsr</gml:identifier>
        <glr:linearElement xlink:href="#Trackline1-cl"/>
        <glr:lrm>
          <glr:LinearReferencingMethod gml:id="Trackline1-lsr-lrm">
            <glr:name>chainage</glr:name>
            <glr:type>absolute</glr:type>
            <glr:units>m</glr:units>
          </glr:LinearReferencingMethod>
        </glr:lrm>
      </LinearSpatialReferenceSystem>
    </linearReferencing>
    <sensorMix>mixed</sensorMix>
    <totalTracklineLength uom="m">500</totalTracklineLength>
  </GP_Trackline>
```

Next, we encode the GeophysicalFieldSurvey measurement feature to reference the GP_Trackline and the processed Test results:

```
<measurement>
  <GeophysicalFieldSurvey gml:id="res0">
    <investigationTarget>Natural Ground</investigationTarget>
    <projectRef xlink:href="#proj1"/>
    <samplingFeatureRef xlink:href="#Trackline-1"/>
    <processedGeophysicalResultsRef xlink:href="#ProcessedERT"/>
    <outcome>
      <GP_SurveyResult gml:id="res0-results"/>
    </outcome>
    <geophysicalMethod>electrical resistivity tomography (ERT)</geophysicalMethod>
  </GeophysicalFieldSurvey>
</measurement>
```

In the above instance, samplingFeatureRef points to the GP_Trackline and processedGeophysicalResultsRef points to the Test object containing the processed results. Note that the outcome property is mandatory and thus must contain a GP_SurveyResult, although its contents are empty because we are not transferring any “raw” data nor reporting on source or receiver locations.

From this instance example, all that an end user would know about the survey in this scenario is that it was an ERT field survey run along a profile located by GP_Trackline with gml:id="Trackline-1".

Scenario 2: Transfer only "raw" field data

In this scenario, no sampling feature would need to be encoded, the GeophysicalFieldSurvey measurement would be as follows:

```
<measurement>
  <GeophysicalFieldSurvey gml:id="res1">
    <investigationTarget>Natural Ground</investigationTarget>
    <projectRef xlink:href="#proj1"/>
    <processedGeophysicalResultsRef xlink:href="#ProcessedERT"/>
    <outcome>
      <GP_SurveyResult gml:id="res1-results">
        <dataPackage>
          <DataPackage>
            <files>
              <GP_FieldDataFile gml:id="res1-df">
                <gml:description>Zip of Geometrics .ts data files</gml:description>
                <gml:name>Res1.zip</gml:name>
                <fileURL>./res1-df.zip</fileURL>
                <creatingApplication>
                  <SoftwareApplication gml:id="eh5">
                    <gml:name>Geometrics EH5Pro</gml:name>
                  </SoftwareApplication>
                </creatingApplication>
                <mimeType>application/zip</mimeType>
                <compression>gzip</compression>
              </GP_FieldDataFile>
            </files>
          </DataPackage>
        </dataPackage>
      </GP_SurveyResult>
    </outcome>
    <geophysicalMethod>electrical resistivity tomography (ERT)</geophysicalMethod>
  </GeophysicalFieldSurvey>
</measurement>
```

Note that there is no samplingFeatureRef property in this scenario. All an end user would receive is the data package that was used to produce the processed results encoded in the Test object with ID="ProcessedERT". No other metadata about the field survey would be transferred except what might be included in the data package itself.

Scenario 3: Transfer the data files, trackline and source/receiver locations

In this scenario, GeophysicalFieldSurvey would include the samplingFeatureRef property and instantiate the gp_Location property as follows:

```
<measurement>
  <GeophysicalFieldSurvey gml:id="res3">
    <investigationTarget>Natural Ground</investigationTarget>
    <projectRef xlink:href="#proj1"/>
    <samplingFeatureRef xlink:href="#Trackline-1"/>
    <outcome>
      <GP_SurveyResult gml:id="res3-results">
        <gp_Location>
          <GP_Location>
            <receiverLocations>
              <MultiPointLocation gml:id="res3-rl" srsName="#Trackline1-lsr" srsDimension="1">
                <gml:posList>230 270</gml:posList>
              </MultiPointLocation>
            </receiverLocations>
            <sourceLocations>
              <MultiPointLocation gml:id="res3-sl" srsName="#Trackline1-lsr"  srsDimension="1">
                <gml:posList>0 50 100 150 200 300 350 400 450 500</gml:posList>
              </MultiPointLocation>
            </sourceLocations>
          </GP_Location>
        </gp_Location>
```

```xml
            <dataPackage>
              <DataPackage>
                <files>
                  <GP_FieldDataFile gml:id="res3-df">
                    <gml:description>Zip of Geometrics .ts data files</gml:description>
                    <gml:name>Res1.zip</gml:name>
                    <fileURL>http://myserver.com/data/res1-df.zip</fileURL>
                    <creatingApplication>
                      <SoftwareApplication gml:id="eh5-1">
                        <gml:name>Geometrics EH5Pro</gml:name>
                      </SoftwareApplication>
                    </creatingApplication>
                    <mimeType>application/zip</mimeType>
                  </GP_FieldDataFile>
                </files>
              </DataPackage>
            </dataPackage>
          </GP_SurveyResult>
        </outcome>
        <geophysicalMethod>electrical resistivity tomography (ERT)</geophysicalMethod>
      </GeophysicalFieldSurvey>
    </measurement>
```

The end user in this scenario would be able to visualize the trackline location and all the positions that the sensors occupied during the survey (Figure 5B). The individual source or receivers, however, would not be identified nor is any information about the movement of the various sensors throughout the survey transferred.

Scenario 4. All available metadata transferred

Transfer of all the additional available data about the field survey requires inclusion of the procedure property as follows:

```xml
    <measurement>
.
. <!—XML elements from Scenario 3 above

        <geophysicalMethod>electrical resistivity tomography (ERT)</geophysicalMethod>
        <procedure>
          <GP_FieldProcedure gml:id="res3-fp">
            <gml:description>Electrical resistivity survey (Schlumberger Array)</gml:description>
            <receiverEquipment>
              <GP_Receiver gml:id="P1">
                <class>voltage electrode</class>
                <serialNumber>12345</serialNumber>
                <otherEquipmentProperty>
                  <Parameter>
                    <parameterName>electrode material</parameterName>
                    <parameterValue>stainless steel</parameterValue>
                  </Parameter>
                </otherEquipmentProperty>
                <receiverType>electrode</receiverType>
                <isGroup>false</isGroup>
              </GP_Receiver>
            </receiverEquipment>
            <receiverEquipment>
              <GP_Receiver gml:id="P2">
                <class>voltage electrode</class>
                <serialNumber>12346</serialNumber>
                <otherEquipmentProperty>
                  <Parameter>
                    <parameterName>electrode material</parameterName>
                    <parameterValue>stainless steel</parameterValue>
                  </Parameter>
                </otherEquipmentProperty>
                <receiverType>electrode</receiverType>
                <isGroup>false</isGroup>
```

```xml
    </GP_Receiver>
  </receiverEquipment>
  <sourceEquipment>
    <GP_Source gml:id="C1">
      <class>current electrode</class>
      <serialNumber>23456</serialNumber>
      <otherEquipmentProperty>
        <Parameter>
          <parameterName>electrode material</parameterName>
          <parameterValue>stainless steel</parameterValue>
        </Parameter>
      </otherEquipmentProperty>
      <sourceType>nonimpulsive</sourceType>
      <isGroup>false</isGroup>
    </GP_Source>
  </sourceEquipment>
  <sourceEquipment>
    <GP_Source gml:id="C2">
      <class>current electrode</class>
      <serialNumber>23457</serialNumber>
      <otherEquipmentProperty>
        <Parameter>
          <parameterName>electrode material</parameterName>
          <parameterValue>stainless steel</parameterValue>
        </Parameter>
      </otherEquipmentProperty>
      <sourceType>nonimpulsive</sourceType>
      <isGroup>false</isGroup>
    </GP_Source>
  </sourceEquipment>
  <configurations>
    <Configuration>
      <receiverInfo>
        <ReceiverInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noReceiverStations>2</noReceiverStations>
          <noReceivers>2</noReceivers>
          <receiverLocations>
            <ReceiverLocations gml:id="res3-fp-rg">
              <receiverRef xlink:href="#P1"/>
              <receiverRef xlink:href="#P2"/>
              <locations>
                <MultiPointLocation gml:id="res3-fp-r" srsName="#Trackline1-lsr" srsDimension="1">
                 <gml:posList>230 270</gml:posList>
                </MultiPointLocation>
              </locations>
            </ReceiverLocations>
          </receiverLocations>
        </ReceiverInfo>
      </receiverInfo>
      <sourceInfo>
        <SourceInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noSourceStations>2</noSourceStations>
          <noSources>2</noSources>
          <sourceLocations>
            <SourceLocations gml:id="res3-fp-sg">
              <sourceRef xlink:href="#C1"/>
              <sourceRef xlink:href="#C2"/>
              <locations>
                <MultiPointLocation gml:id="res3-fp-s" srsName="#Trackline1-lsr" srsDimension="1">
                 <gml:posList>200 300</gml:posList>
                </MultiPointLocation>
              </locations>
            </SourceLocations>
          </sourceLocations>
        </SourceInfo>
      </sourceInfo>
    </Configuration>
    <Configuration>
      <receiverInfo>
```

```xml
        <ReceiverInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noReceiverStations>2</noReceiverStations>
          <noReceivers>2</noReceivers>
          <receiverLocations xlink:href="#res3-fp-rg"/>
        </ReceiverInfo>
      </receiverInfo>
      <sourceInfo>
        <SourceInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noSourceStations>2</noSourceStations>
          <noSources>2</noSources>
          <sourceLocations>
            <SourceLocations gml:id="res3-fp-sg2">
              <sourceRef xlink:href="#C1"/>
              <sourceRef xlink:href="#C2"/>
              <locations>
                <MultiPointLocation gml:id="res3-fp-s2" srsName="#Trackline1-lsr" srsDimension="1">
                  <gml:posList>150 350</gml:posList>
                </MultiPointLocation>
              </locations>
            </SourceLocations>
          </sourceLocations>
        </SourceInfo>
      </sourceInfo>
    </Configuration>
    <Configuration>
      <receiverInfo>
        <ReceiverInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noReceiverStations>2</noReceiverStations>
          <noReceivers>2</noReceivers>
          <receiverLocations xlink:href="#res3-fp-rg"/>
        </ReceiverInfo>
      </receiverInfo>
      <sourceInfo>
        <SourceInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noSourceStations>2</noSourceStations>
          <noSources>2</noSources>
          <sourceLocations>
            <SourceLocations gml:id="res3-fp-rg3">
              <sourceRef xlink:href="#C1"/>
              <sourceRef xlink:href="#C2"/>
              <locations>
                <MultiPointLocation gml:id="res3-fp-s3" srsName="#Trackline1-lsr" srsDimension="1">
                  <gml:posList>100 400</gml:posList>
                </MultiPointLocation>
              </locations>
            </SourceLocations>
          </sourceLocations>
        </SourceInfo>
      </sourceInfo>
    </Configuration>
    <Configuration>
      <receiverInfo>
        <ReceiverInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noReceiverStations>2</noReceiverStations>
          <noReceivers>2</noReceivers>
          <receiverLocations xlink:href="#res3-fp-rg"/>
        </ReceiverInfo>
      </receiverInfo>
      <sourceInfo>
        <SourceInfo>
          <samplingFeatureRef xlink:href="#Trackline-1"/>
          <noSourceStations>2</noSourceStations>
          <noSources>2</noSources>
          <sourceLocations>
            <SourceLocations gml:id="res3-fp-sg4">
              <sourceRef xlink:href="#C1"/>
```

```xml
                <sourceRef xlink:href="#C2"/>
                <locations>
                  <MultiPointLocation gml:id="res3-fp-s4" srsName="#Trackline1-lsr" srsDimension="1">
                   <gml:posList>50 450</gml:posList>
                  </MultiPointLocation>
                </locations>
              </SourceLocations>
            </sourceLocations>
          </SourceInfo>
        </sourceInfo>
      </Configuration>
      <Configuration>
        <receiverInfo>
          <ReceiverInfo>
            <samplingFeatureRef xlink:href="#Trackline-1"/>
            <noReceiverStations>2</noReceiverStations>
            <noReceivers>2</noReceivers>
            <receiverLocations xlink:href="#res3-fp-rg"/>
          </ReceiverInfo>
        </receiverInfo>
        <sourceInfo>
          <SourceInfo>
            <samplingFeatureRef xlink:href="#Trackline-1"/>
            <noSourceStations>2</noSourceStations>
            <noSources>2</noSources>
            <sourceLocations>
              <SourceLocations gml:id="res3-fp-sg5">
                <sourceRef xlink:href="#C1"/>
                <sourceRef xlink:href="#C2"/>
                <locations>
                  <MultiPointLocation gml:id="res3-fp-s5" srsName="#Trackline1-lsr" srsDimension="1">
                   <gml:posList>0 500</gml:posList>
                  </MultiPointLocation>
                </locations>
              </SourceLocations>
            </sourceLocations>
          </SourceInfo>
        </sourceInfo>
      </Configuration>
    </configurations>
   </GP_FieldProcedure>
  </procedure>
 </GeophysicalFieldSurvey>
</measurement>
```

In the above example, information about each of the individual sensors are encoded into the GP_Receiver or GP_Source objects, for example:

```xml
<GP_Source gml:id="C1">
  <class>current electrode</class>
  <serialNumber>23456</serialNumber>
  <otherEquipmentProperty>
    <Parameter>
      <parameterName>electrode material</parameterName>
      <parameterValue>stainless steel</parameterValue>
    </Parameter>
  </otherEquipmentProperty>
  <sourceType>nonimpulsive</sourceType>
  <isGroup>false</isGroup>
</GP_Source>
```

Next are the configuration objects that expose the geometries of the sources and receivers at each step (configuration) of the survey process. The following ReceiverInfo object within the first configuration illustrates how specific receivers are linked to a location:

```xml
<ReceiverInfo>
  <samplingFeatureRef xlink:href="#Trackline-1"/>
  <noReceiverStations>2</noReceiverStations>
```

```
                <noReceivers>2</noReceivers>
                <receiverLocations>
                    <ReceiverLocations gml:id="res3-fp-rg">
                        <receiverRef xlink:href="#P1"/>
                        <receiverRef xlink:href="#P2"/>
                        <locations>
                            <MultiPointLocation gml:id="res3-fp-r"srsName="#Trackline1-lsr" srsDimension="1">
                              <gml:posList>230 270</gml:posList>
                            </MultiPointLocation>
                        </locations>
                    </ReceiverLocations>
                </receiverLocations>
            </ReceiverInfo>
        </receiverInfo>
```

The values of the noReceivers and noReceiverStations properties indicate that there are two specific receivers positioned at a total of 2 locations. The receiverRef properties point to the P1 and P2 GP_Receiver in list order and the individual locations in the gml:posList property of the MultiPointLocation object identify their locations at 230 m and 270 m respectively – in other words the first receiverRef property corresponds to the first location in gml:PosList, the second receiverRef property corresponds with the second position and so forth. This is done within all of the ReceiverInfo and SourceInfo objects within each Configuration object.

Example 2 – Hypothetical 3D seismic refraction survey

In this example, we look at a simple representation of a 3D seismic survey (Figure 6). Twenty-one geophones (blue squares, labeled G1 through G21) are laid out along 3 parallel lines (T1, T2 and T3) and a hammer and rubber strike plate is used as the energy source with strikes occurring at 12 locations (red triangles) on three crossing lines (SA, SB, and SC).

Because data from all of the lines will be processed to obtain the final results, the lines can be modeled as a single GP_MultiTrack sampling feature containing 6 GP_Trackline objects. Because the overall source-receiver geometry does not change through the duration of the survey, this is modeled as a single Configuration.

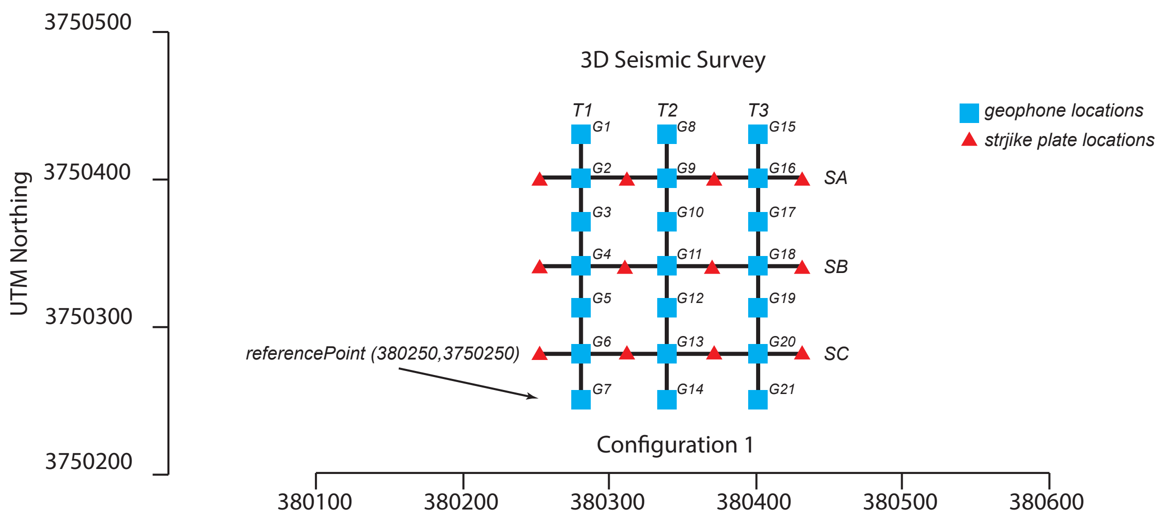

Figure 6. Hypothetical 3D seismic survey consisting of a single GP_MultiTrack sampling feature with six component GP_Tracklines (T1, T2, T3, SA, SB, SC). The survey utilizes a group of 21 geophones, one at each receiver station (blue squares) and a hammer and strike plate energy source that is deployed at 12 locations along the SA, SB and SC tracks (red triangles). The array comprises one configuration.

SamplingFeature encoding

The resultant GP_Multitrack instance is as follows:


```
<samplingFeature>
  <GP_MultiTrack gml:id="Multitrack">
    <gml:name>3DSurvey Tracks</gml:name>
    <investigationTarget>Natural Ground</investigationTarget>
    <projectRef xlink:href="#proj2"/>
    <referencePoint>
      <PointLocation gml:id="Multitrack-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
        <gml:pos>380250 3750250</gml:pos>
      </PointLocation>
    </referencePoint>
    <trackline>
      <GP_Trackline gml:id="T1">
        <gml:name>T1</gml:name>
        <investigationTarget>Natural Ground</investigationTarget>
        <projectRef xlink:href="#proj2"/>
        <referencePoint>
          <PointLocation gml:id="T1-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:pos>380280 3750430</gml:pos>
          </PointLocation>
        </referencePoint>
        <centerLine>
          <LinearExtent gml:id="T1-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:posList>380280 3750430 380280 3750250</gml:posList>
          </LinearExtent>
        </centerLine>
        <linearReferencing>
          <LinearSpatialReferenceSystem gml:id="T1-lsr">
            <gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS">DIGGS:T1-lsr</gml:identifier>
            <glr:linearElement xlink:href="#T1-cl"/>
            <glr:lrm>
              <glr:LinearReferencingMethod gml:id="T1-lsr-lrm">
                <glr:name>chainage</glr:name>
                <glr:type>absolute</glr:type>
                <glr:units>m</glr:units>
              </glr:LinearReferencingMethod>
            </glr:lrm>
          </LinearSpatialReferenceSystem>
        </linearReferencing>
        <sensorMix>receivers</sensorMix>
        <totalTracklineLength uom="m">180</totalTracklineLength>
      </GP_Trackline>
    </trackline>
    <trackline>
      <GP_Trackline gml:id="T2">
        <gml:name>T2</gml:name>
        <investigationTarget>Natural Ground</investigationTarget>
        <projectRef xlink:href="#proj2"/>
        <referencePoint>
          <PointLocation gml:id="T2-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:pos>380340 3750430</gml:pos>
          </PointLocation>
        </referencePoint>
        <centerLine>
          <LinearExtent gml:id="T2-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:posList>380340 3750430 380340 3750250</gml:posList>
          </LinearExtent>
        </centerLine>
        <linearReferencing>
          <LinearSpatialReferenceSystem gml:id="T2-lsr">
            <gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS">DIGGS:T2-lsr</gml:identifier>
            <glr:linearElement xlink:href="#T2-cl"/>
            <glr:lrm>
              <glr:LinearReferencingMethod gml:id="T2-lsr-lrm">
                <glr:name>chainage</glr:name>
                <glr:type>absolute</glr:type>
```

```xml
                &lt;glr:units&gt;m&lt;/glr:units&gt;
              &lt;/glr:LinearReferencingMethod&gt;
            &lt;/glr:lrm&gt;
          &lt;/LinearSpatialReferenceSystem&gt;
        &lt;/linearReferencing&gt;
        &lt;sensorMix&gt;receivers&lt;/sensorMix&gt;
        &lt;totalTracklineLength uom="m"&gt;180&lt;/totalTracklineLength&gt;
      &lt;/GP_Trackline&gt;
    &lt;/trackline&gt;
    &lt;trackline&gt;
      &lt;GP_Trackline gml:id="T3"&gt;
        &lt;gml:name&gt;T3&lt;/gml:name&gt;
        &lt;investigationTarget&gt;Natural Ground&lt;/investigationTarget&gt;
        &lt;projectRef xlink:href="#proj2"/&gt;
        &lt;referencePoint&gt;
          &lt;PointLocation gml:id="T3-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911"&gt;
            &lt;gml:pos&gt;380400 3750430&lt;/gml:pos&gt;
          &lt;/PointLocation&gt;
        &lt;/referencePoint&gt;
        &lt;centerLine&gt;
          &lt;LinearExtent gml:id="T3-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911"&gt;
            &lt;gml:posList&gt;380400 3750430 380400 3750250&lt;/gml:posList&gt;
          &lt;/LinearExtent&gt;
        &lt;/centerLine&gt;
        &lt;linearReferencing&gt;
          &lt;LinearSpatialReferenceSystem gml:id="T3-lsr"&gt;
            &lt;gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS"&gt;DIGGS:T3-lsr&lt;/gml:identifier&gt;
            &lt;glr:linearElement xlink:href="#T3-cl"/&gt;
            &lt;glr:lrm&gt;
              &lt;glr:LinearReferencingMethod gml:id="T3-lsr-lrm"&gt;
                &lt;glr:name&gt;chainage&lt;/glr:name&gt;
                &lt;glr:type&gt;absolute&lt;/glr:type&gt;
                &lt;glr:units&gt;m&lt;/glr:units&gt;
              &lt;/glr:LinearReferencingMethod&gt;
            &lt;/glr:lrm&gt;
          &lt;/LinearSpatialReferenceSystem&gt;
        &lt;/linearReferencing&gt;
        &lt;sensorMix&gt;receivers&lt;/sensorMix&gt;
        &lt;totalTracklineLength uom="m"&gt;180&lt;/totalTracklineLength&gt;
      &lt;/GP_Trackline&gt;
    &lt;/trackline&gt;
    &lt;trackline&gt;
      &lt;GP_Trackline gml:id="SA"&gt;
        &lt;gml:name&gt;SA&lt;/gml:name&gt;
        &lt;investigationTarget&gt;Natural Ground&lt;/investigationTarget&gt;
        &lt;projectRef xlink:href="#proj2"/&gt;
        &lt;referencePoint&gt;
          &lt;PointLocation gml:id="SA-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911"&gt;
            &lt;gml:pos&gt;380250 3750280&lt;/gml:pos&gt;
          &lt;/PointLocation&gt;
        &lt;/referencePoint&gt;
        &lt;centerLine&gt;
          &lt;LinearExtent gml:id="SA-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911"&gt;
            &lt;gml:posList&gt;380250 3750280 380430 3750280&lt;/gml:posList&gt;
          &lt;/LinearExtent&gt;
        &lt;/centerLine&gt;
        &lt;linearReferencing&gt;
          &lt;LinearSpatialReferenceSystem gml:id="SA-lsr"&gt;
            &lt;gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS"&gt;DIGGS:SA-lsr&lt;/gml:identifier&gt;
            &lt;glr:linearElement xlink:href="#SA-cl"/&gt;
            &lt;glr:lrm&gt;
              &lt;glr:LinearReferencingMethod gml:id="SA-lsr-lrm"&gt;
                &lt;glr:name&gt;chainage&lt;/glr:name&gt;
                &lt;glr:type&gt;absolute&lt;/glr:type&gt;
                &lt;glr:units&gt;m&lt;/glr:units&gt;
              &lt;/glr:LinearReferencingMethod&gt;
            &lt;/glr:lrm&gt;
          &lt;/LinearSpatialReferenceSystem&gt;
        &lt;/linearReferencing&gt;
        &lt;sensorMix&gt;sources&lt;/sensorMix&gt;
        &lt;totalTracklineLength uom="m"&gt;180&lt;/totalTracklineLength&gt;
```

```xml
      </GP_Trackline>
    </trackline>
    <trackline>
      <GP_Trackline gml:id="SB">
        <gml:name>SA</gml:name>
        <investigationTarget>Natural Ground</investigationTarget>
        <projectRef xlink:href="#proj2"/>
        <referencePoint>
          <PointLocation gml:id="SB-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:pos>380250 3750340</gml:pos>
          </PointLocation>
        </referencePoint>
        <centerLine>
          <LinearExtent gml:id="SB-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:posList>380250 3750340 380430 3750340</gml:posList>
          </LinearExtent>
        </centerLine>
        <linearReferencing>
          <LinearSpatialReferenceSystem gml:id="SB-lsr">
            <gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS">DIGGS:SB-lsr</gml:identifier>
            <glr:linearElement xlink:href="#SB-cl"/>
            <glr:lrm>
              <glr:LinearReferencingMethod gml:id="SB-lsr-lrm">
                <glr:name>chainage</glr:name>
                <glr:type>absolute</glr:type>
                <glr:units>m</glr:units>
              </glr:LinearReferencingMethod>
            </glr:lrm>
          </LinearSpatialReferenceSystem>
        </linearReferencing>
        <sensorMix>sources</sensorMix>
        <totalTracklineLength uom="m">180</totalTracklineLength>
      </GP_Trackline>
    </trackline>
    <trackline>
      <GP_Trackline gml:id="SC">
        <gml:name>SA</gml:name>
        <investigationTarget>Natural Ground</investigationTarget>
        <projectRef xlink:href="#proj2"/>
        <referencePoint>
          <PointLocation gml:id="SC-rp" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:pos>380250 3750400</gml:pos>
          </PointLocation>
        </referencePoint>
        <centerLine>
          <LinearExtent gml:id="SC-cl" srsDimension="2" srsName="http://www.opengis.net/def/crs/EPSG/0/26911">
            <gml:posList>380250 3750400 380430 3750400</gml:posList>
          </LinearExtent>
        </centerLine>
        <linearReferencing>
          <LinearSpatialReferenceSystem gml:id="SC-lsr">
            <gml:identifier codeSpace="http://diggsml.org/def/authorities.xml#DIGGS">DIGGS:SC-lsr</gml:identifier>
            <glr:linearElement xlink:href="#SC-cl"/>
            <glr:lrm>
              <glr:LinearReferencingMethod gml:id="SC-lsr-lrm">
                <glr:name>chainage</glr:name>
                <glr:type>absolute</glr:type>
                <glr:units>m</glr:units>
              </glr:LinearReferencingMethod>
            </glr:lrm>
          </LinearSpatialReferenceSystem>
        </linearReferencing>
        <sensorMix>sources</sensorMix>
        <totalTracklineLength uom="m">180</totalTracklineLength>
      </GP_Trackline>
    </trackline>
  </GP_MultiTrack>
</samplingFeature>
```

GeophysicalFieldSurvey encoding

The GP_SurveyResult object for this scenario is similar to that for the ERT survey:

```
  <measurement>
    <GeophysicalFieldSurvey gml:id="seis">
      <investigationTarget>Natural Ground</investigationTarget>
      <projectRef xlink:href="#proj2"/>
      <samplingFeatureRef xlink:href="#Multitrack"/>
      <outcome>
        <GP_SurveyResult gml:id="seis-sr">
          <dataPackage>
            <DataPackage>
              <files>
                <GP_FieldDataFile gml:id="seis-df">
                  <gml:name>seis1.zip</gml:name>
                  <fileURL>http://myserver.com/data/seis1-df.zip</fileURL>
                  <mimeType>application/zip</mimeType>
                </GP_FieldDataFile>
              </files>
            </DataPackage>
          </dataPackage>
        </GP_SurveyResult>
      </outcome>
      <geophysicalMethod>seismic reflection</geophysicalMethod>
.
```

For the GP_FieldProcedure object, there is one GP_Source (hammer and strike plate) and one GP_Receiver object used for the 21 geophones because they are all functionally identical and can be treated as a group:

```
        <GP_FieldProcedure gml:id="seis-fp">
          <gml:description>Grid array of 21 geophones connected to Geometrics Geode Exploration
seismograph</gml:description>
          <receiverEquipment>
            <GP_Receiver gml:id="geophone-1-21">
              <gml:description>All 21 geophones in this survey are treated as a group as all are functionally
identical</gml:description>
              <otherEquipmentProperty>
                <Parameter>
                  <parameterName>geophone frequency</parameterName>
                  <parameterValue>4.5</parameterValue>
                  <parameterUnits>Hz</parameterUnits>
                </Parameter>
              </otherEquipmentProperty>
              <receiverType>geophone</receiverType>
              <isGroup noReceivers="21">true</isGroup>
            </GP_Receiver>
          </receiverEquipment>
          <sourceEquipment>
            <GP_Source gml:id="hammer">
              <gml:description>20 lb sledge hammer using rubber strike plate</gml:description>
              <otherEquipmentProperty>
                <Parameter>
                  <parameterName>hammer weight</parameterName>
                  <parameterValue>20</parameterValue>
                  <parameterUnits>lbf</parameterUnits>
                </Parameter>
              </otherEquipmentProperty>
              <otherEquipmentProperty>
                <Parameter>
                  <parameterName>strike plate type</parameterName>
                  <parameterValue>rubber</parameterValue>
                </Parameter>
              </otherEquipmentProperty>
              <sourceType>impulsive</sourceType>
              <isGroup>false</isGroup>
            </GP_Source>
          </sourceEquipment>
.
```

In this example there is only one Configuration object needed, but it is more complex than that for the ERT survey as there needs to be three ReceiverInfo objects (one for each line T1, T2, and T3) and three SourceInfo objects (one for each line SA, SB, and S).


```xml
<configurations>
  <Configuration>
    <receiverInfo>
      <ReceiverInfo>
        <samplingFeatureRef xlink:href="#T1"/>
        <receiverSpacing>
          <SensorSpacing>
            <minSpacing uom="m">30</minSpacing>
            <maxSpacing uom="m">30</maxSpacing>
          </SensorSpacing>
        </receiverSpacing>
        <noReceiverStations>7</noReceiverStations>
        <noReceivers>7</noReceivers>
        <receiverLocations>
          <ReceiverLocations gml:id="seis-t1-rg">
            <receiverRef xlink:href="#geophone-1-21"/>
            <locations>
              <MultiPointLocation gml:id="seis-t1" srsDimension="1" srsName="#T1-lsr">
               <gml:posList>0 30 60 90 120 150 180</gml:posList>
              </MultiPointLocation>
            </locations>
          </ReceiverLocations>
        </receiverLocations>
      </ReceiverInfo>
      <ReceiverInfo>
        <samplingFeatureRef xlink:href="#T2"/>
        <receiverSpacing>
          <SensorSpacing>
            <minSpacing uom="m">30</minSpacing>
            <maxSpacing uom="m">30</maxSpacing>
          </SensorSpacing>
        </receiverSpacing>
        <noReceiverStations>7</noReceiverStations>
        <noReceivers>7</noReceivers>
        <receiverLocations>
          <ReceiverLocations gml:id="seis-t2-rg">
            <receiverRef xlink:href="#geophone-1-21"/>
            <locations>
              <MultiPointLocation gml:id="seis-t2" srsDimension="1" srsName="#T2-lsr">
               <gml:posList>0 30 60 90 120 150 180</gml:posList>
              </MultiPointLocation>
            </locations>
          </ReceiverLocations>
        </receiverLocations>
      </ReceiverInfo>
      <ReceiverInfo>
        <samplingFeatureRef xlink:href="#T3"/>
        <receiverSpacing>
          <SensorSpacing>
            <minSpacing uom="m">30</minSpacing>
            <maxSpacing uom="m">30</maxSpacing>
          </SensorSpacing>
        </receiverSpacing>
        <noReceiverStations>7</noReceiverStations>
        <noReceivers>7</noReceivers>
        <receiverLocations>
          <ReceiverLocations gml:id="seis-t3-rg">
            <receiverRef xlink:href="#geophone-1-21"/>
            <locations>
              <MultiPointLocation gml:id="seis-t3" srsDimension="1" srsName="#T3-lsr">
               <gml:posList>0 30 60 90 120 150 180</gml:posList>
              </MultiPointLocation>
            </locations>
          </ReceiverLocations>
        </receiverLocations>
      </ReceiverInfo>
```

```xml
            </receiverInfo>
            <sourceInfo>
              <SourceInfo>
                <samplingFeatureRef xlink:href="#SA"/>
                <sourceSpacing>
                  <SensorSpacing>
                    <minSpacing uom="m">60</minSpacing>
                    <maxSpacing uom="m">60</maxSpacing>
                  </SensorSpacing>
                </sourceSpacing>
                <noSourceStations>4</noSourceStations>
                <noSources>1</noSources>
                <sourceLocations>
                  <SourceLocations gml:id="seis-sa-sg">
                    <sourceRef xlink:href="#hammer"/>
                    <locations>
                      <MultiPointLocation gml:id="seis-sa-s" srsDimension="1" srsName="#SA-lsr">
                       <gml:posList>0 60 120 180</gml:posList>
                      </MultiPointLocation>
                    </locations>
                  </SourceLocations>
                </sourceLocations>
              </SourceInfo>
              <SourceInfo>
                <samplingFeatureRef xlink:href="#SB"/>
                <sourceSpacing>
                  <SensorSpacing>
                    <minSpacing uom="m">60</minSpacing>
                    <maxSpacing uom="m">60</maxSpacing>
                  </SensorSpacing>
                </sourceSpacing>
                <noSourceStations>4</noSourceStations>
                <noSources>1</noSources>
                <sourceLocations>
                  <SourceLocations gml:id="seis-sb-sg">
                    <sourceRef xlink:href="#hammer"/>
                    <locations
                      <MultiPointLocation gml:id="seis-sb-s" srsDimension="1" srsName="#SB-lsr">
                       <gml:posList>0 60 120 180</gml:posList>
                      </MultiPointLocation>
                    </locations>
                  </SourceLocations>
                </sourceLocations>
              </SourceInfo>
              <SourceInfo>
                <samplingFeatureRef xlink:href="#SC"/>
                <sourceSpacing>
                  <SensorSpacing>
                    <minSpacing uom="m">60</minSpacing>
                    <maxSpacing uom="m">60</maxSpacing>
                  </SensorSpacing>
                </sourceSpacing>
                <noSourceStations>4</noSourceStations>
                <noSources>1</noSources>
                <sourceLocations>
                  <SourceLocations gml:id="seis-sc-sg">
                    <sourceRef xlink:href="#hammer"/>
                    <locations>
                      <MultiPointLocation gml:id="seis-sc-s"  srsDimension="1" srsName="#SC-lsr">
                       <gml:posList>0 60 120 180</gml:posList>
                      </MultiPointLocation>
                    </locations>
                  </SourceLocations>
                </sourceLocations>
              </SourceInfo>
            </sourceInfo>
          </Configuration>
        </configurations>
      </GP_FieldProcedure>
    </procedure>
</GeophysicalFieldSurvey>
```

```xml
</measurement>
```

In this example,, there is no direct mapping between specific receivers and their locations because the 21 receivers are treated as a group, as demonstrated by the ReceiverInfo object associated with GP_Trackline for T1:

```xml
<ReceiverInfo>
  <samplingFeatureRef xlink:href="#T1"/>
  <receiverSpacing>
    <SensorSpacing>
      <minSpacing uom="m">30</minSpacing>
      <maxSpacing uom="m">30</maxSpacing>
    </SensorSpacing>
  </receiverSpacing>
  <noReceiverStations>7</noReceiverStations>
  <noReceivers>7</noReceivers>
  <receiverLocations>
    <ReceiverLocations gml:id="seis-t1-rg">
      <receiverRef xlink:href="#geophone-1-21"/>
      <locations>
        <MultiPointLocation gml:id="seis-t1" srsDimension="1" srsName="#T1-lsr">
         <gml:posList>0 30 60 90 120 150 180</gml:posList>
        </MultiPointLocation>
      </locations>
    </ReceiverLocations>
  </receiverLocations>
</ReceiverInfo>
```

Note that the value for both noReceivers and noReceiverStations is 7 for this trackline, and that there are 7 locations in the gml:posList property, but only one receiverRef (to the group GP_Receiver). Because both noReceiverStations and noReceivers are the same value, this demonstrates that there is one receiver located at each position (they do not move), even though the individual geophones are not identified here.

There is, however one GP_Source (the hammer and strike plate) that is moved to each sourceLocation during the survey:

```xml
<SourceInfo>
  <samplingFeatureRef xlink:href="#SA"/>
  <sourceSpacing>
    <SensorSpacing>
      <minSpacing uom="m">60</minSpacing>
      <maxSpacing uom="m">60</maxSpacing>
    </SensorSpacing>
  </sourceSpacing>
  <noSourceStations>4</noSourceStations>
  <noSources>1</noSources>
  <sourceLocations>
    <SourceLocations gml:id="seis-sa-sg">
      <sourceRef xlink:href="#hammer"/>
      <locations>
        <MultiPointLocation gml:id="seis-sa-s"srsDimension="1" srsName="#SA-lsr">
         <gml:posList>0 60 120 180</gml:posList>
        </MultiPointLocation>
      </locations>
    </SourceLocations>
  </sourceLocations>
</SourceInfo>
```

Here it can be seen that the value of noSources is 1 while the value of noSourceStations is 4 and there are 4 positions in gml:posList (one for each source location on the trackline. As there is only one GP_Source, this indicates that the source is moved to each source location

Note: GP_FieldProcedure is not configured to everywhere account for the specifics of what source location is associated with any specific receiver configuration. This level of detail would (presumably) be contained in the data package.

Example 3 – Use of the Platform object

As discussed previously, the Platform object is used for field surveys where the receiver and/or receiver-source configuration remains fixed while the entire configuration moves through the sampling space as a unit. One example of this type of survey is the use of an OYO suspension logger to obtain p- and s-wave velocities in boreholes (Figure 7). The unit is a 7 m-long tool that contains within in a source device and two geophone receivers aligned along the tool's length parallel to the direction of tool travel. In this hypothetical example, our field procedure ran the tool in Borehole B1, recording time-series data at 0.5 m depth intervals between the depths of 10 and 5 meters. A representative instance is as follows:

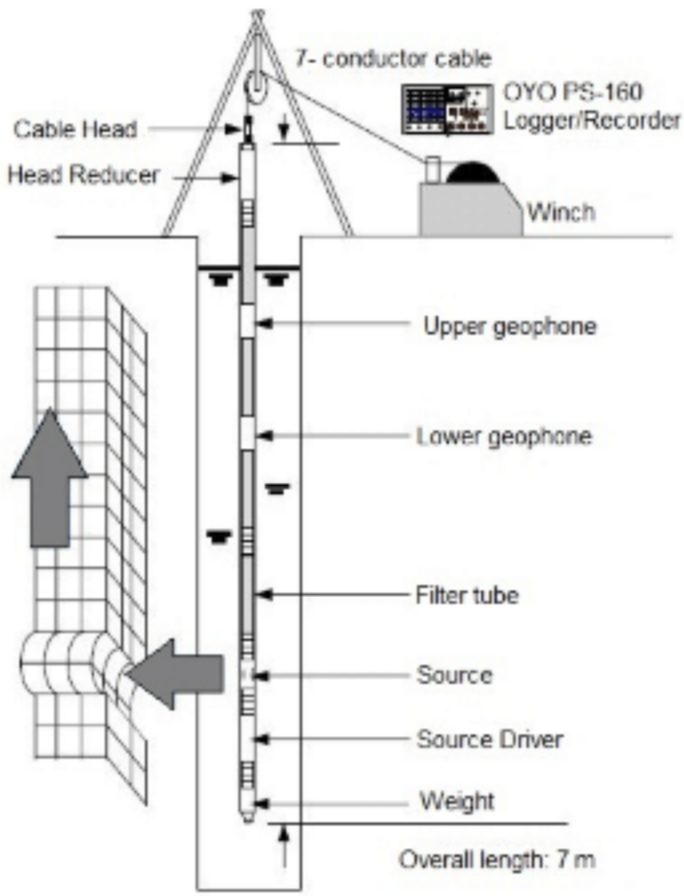

Figure 7. Illustration of an OYO Suspension Logging tool for determining p- and s-wave velocity within a borehole as an example of a Platform (from Garofalo and others, 2016). It consists of one source and two receivers arranged parallel to the direction of platform travel. The tool is moved up the hole during the survey, stopping at specific depths to take measurements.


```
<measurement>
  <GeophysicalFieldSurvey gml:id="oyo">
    <gml:description>OYO suspension logging in borehole B-1</gml:description>
    <investigationTarget>Natural Ground</investigationTarget>
```

```xml
      &lt;projectRef xlink:href="#proj1"/&gt;
      &lt;samplingFeatureRef xlink:href="#B1"/&gt;
      &lt;outcome&gt;
        &lt;GP_SurveyResult gml:id="oyo-result"/&gt;
        &lt;!-- Result not shown here --&gt;
      &lt;/outcome&gt;
      &lt;geophysicalMethod&gt;borehole seismic downhole source&lt;/geophysicalMethod&gt;
      &lt;procedure&gt;
        &lt;GP_FieldProcedure gml:id="oyo-proc"&gt;
          &lt;dataAcquisitionSystem&gt;
            &lt;GP_DataAcquisitionSystem gml:id="oyo-equip"&gt;
              &lt;gml:name&gt;OYO Suspension Logging Tool&lt;/gml:name&gt;
              &lt;modelNumber&gt;OYO PS-160&lt;/modelNumber&gt;
            &lt;/GP_DataAcquisitionSystem&gt;
          &lt;/dataAcquisitionSystem&gt;
          &lt;platforms&gt;
            &lt;Platform&gt;
              &lt;receiverType&gt;geophone&lt;/receiverType&gt;
              &lt;noReceivers&gt;2&lt;/noReceivers&gt;
              &lt;receiverArrayOrientation&gt;parallel&lt;/receiverArrayOrientation&gt;
              &lt;receiverSpacing&gt;
                &lt;SensorSpacing&gt;
                  &lt;minSpacing uom="m"&gt;1.5&lt;/minSpacing&gt;
                  &lt;maxSpacing uom="m"&gt;1.5&lt;/maxSpacing&gt;
                &lt;/SensorSpacing&gt;
              &lt;/receiverSpacing&gt;
              &lt;sourceType&gt;impulsive&lt;/sourceType&gt;
              &lt;noSources&gt;1&lt;/noSources&gt;
              &lt;sourceReceiverOrientation&gt;parallel&lt;/sourceReceiverOrientation&gt;
              &lt;minSourceReceiverSpacing uom="m"&gt;3&lt;/minSourceReceiverSpacing&gt;
              &lt;maxSourceReceiverSpacing uom="m"&gt;4.5&lt;/maxSourceReceiverSpacing&gt;
              &lt;platformMovement&gt;
                &lt;PlatformMovement&gt;
                  &lt;samplingFeatureRef xlink:href="#Borehole-1"/&gt;
                  &lt;locations&gt;
                    &lt;MultiPointLocation gml:id="oyo-l" srsName="#B1-lsr-lrm" srsDimension="1"&gt;
                      &lt;gml:posList&gt;10 9.5 9 8.5 8 7.5 7 6.5 6 5.5 5&lt;/gml:posList&gt;
                    &lt;/MultiPointLocation&gt;
                  &lt;/locations&gt;
                &lt;/PlatformMovement&gt;
              &lt;/platformMovement&gt;
            &lt;/Platform&gt;
          &lt;/platforms&gt;
        &lt;/GP_FieldProcedure&gt;
      &lt;/procedure&gt;
    &lt;/GeophysicalFieldSurvey&gt;
  &lt;/measurement&gt;
```

Summary

The Phase 2 DIGGS schema extensions represent a significant advance in standardizing geophysical field data transfer and documentation. Through the development of new XML schema objects, this work addresses several critical needs in geophysical data management:

Data Organization and Transfer

- Provides flexible solutions for both simple and complex field survey geometries through the new sampling feature objects (GP_Trackline, GP_MultiTrack, and GP_ArealSurvey)

- Accommodates various data collection scenarios from single-line surveys to complex 3D arrangements

- Enables efficient transfer of raw field data while maintaining links to processed results

Metadata Management

- Introduces the GeophysicalFieldSurvey measurement object to capture comprehensive survey information
- Standardizes documentation of equipment configurations, survey parameters, and field procedures
- Supports detailed tracking of source and receiver geometries essential for data quality assessment

Implementation Flexibility

- Allows users to provide varying levels of metadata detail based on project requirements
- Supports both simple data transfer scenarios and complex full-documentation cases
- Maintains compatibility with existing DIGGS objects while extending capabilities for geophysical applications

The schema extensions are now available for testing at https://diggsml.org/schemas/2.6/Geophysics.xsd, with complete documentation at https://diggsml.org/docs/2.6. These additions complement the Phase 1 work on processed data transfer, creating a comprehensive framework for geophysical data management.

Further development should focus on:

- Testing with diverse real-world datasets
- Gathering feedback from the geophysical and geotechnical communities
- Refining the schema based on implementation experience

These extensions mark an important step toward improved data exchange and interoperability among geological, geotechnical engineering, and geophysical communities, supporting the full lifecycle of geo-engineering projects from initial survey through final archiving.

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