



# Arc Marine

*GIS for a Blue Planet*

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*Foreword by Jane Lubchenco*

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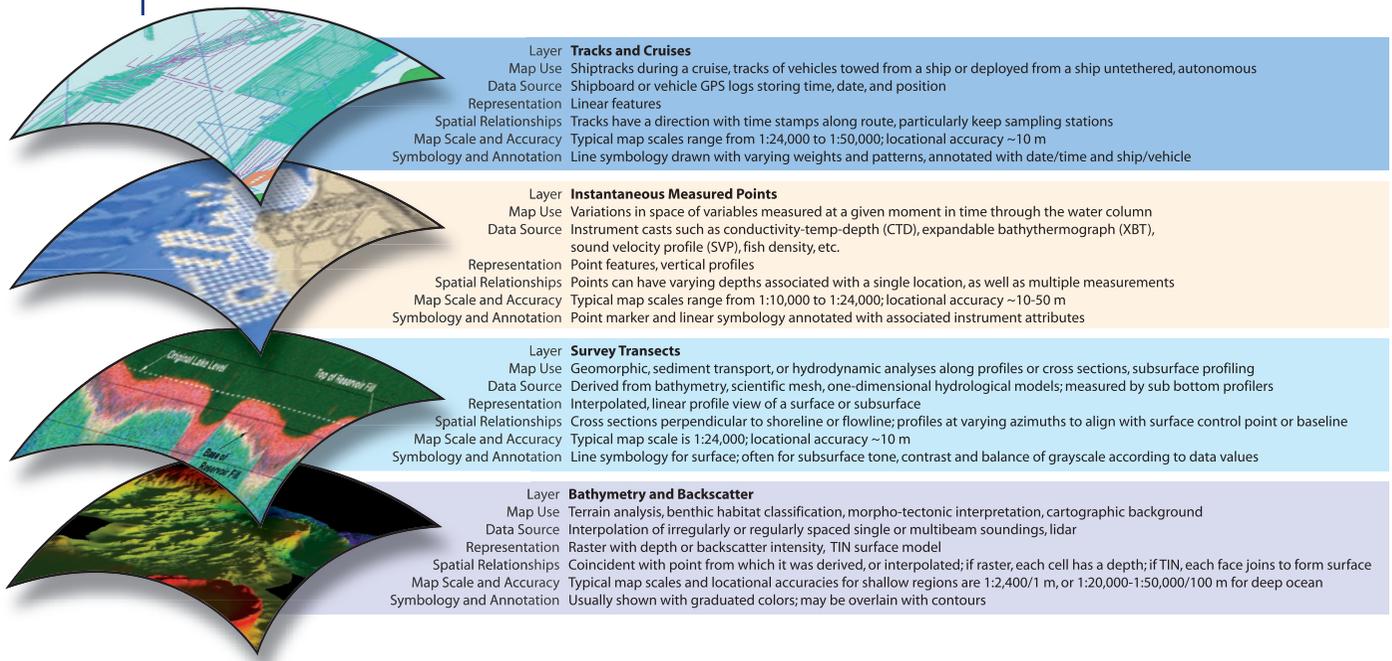
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## Marine surveys

*Marine surveys are the backbone of Arc Marine because of the initial and critical role of data collection within a survey. All too often datasets are collected, analyzed, and “put in a GIS” after the fact. Arc Marine is designed expressly for the planning of marine surveys and the subsequent collection of data at sea. The intended result is the simplification of data management and analysis of survey data that often extends toward hundreds of data gigabytes. This chapter focuses on point datasets, the values those points represent, the measurements taken at various depths of the point, and how they all might be grouped together into a single event, often referred to as a survey. Surveys can be considered a collection of points, ranging in number from tens to billions of points. Survey types can vary, requiring a mechanism for classifying the points accordingly. This chapter also describes the use of line features (e.g., Tracks or ProfileLines) generally associated with a survey, how to store some general information about a survey (e.g., ports of call, names of scientists involved), and how to look at the data, particularly on a Track-by-Track basis. The chapter draws on two case studies: seafloor mapping and geologic sampling by the Woods Hole Science Center of the U.S. Geological Survey (USGS), in order to study the regional geologic framework of the inner continental shelf of Massachusetts; and a marine survey information geodatabase built by Photo Science, Inc., as part of a long-term USGS-led study of subsidence and sea-level rise in southeastern Louisiana (begun prior to Hurricane Katrina and ongoing).*



## Introduction

At the heart of marine science and management is the survey, which focuses on the initial acquisition of marine data, and is thus concerned with the accurate sensing and collection of measurements from the marine environment and their transformation from raw to processed measurements for GIS implementation. Here, data collection is often made in two ways: (1) short-term mobile entities, such as research cruises (day operations in a small survey boat, or 24-hour operations over weeks or months on a larger research vessel), deploying various instruments, instrument platforms, remotely operated vehicles (ROVs), or submersibles; or (2) surveys that put into place longer-term, fixed entities, such as hydrophones, buoys, or various other types of moored instrumentation. These will remain in the ocean or along the shore collecting data for months or even years (the ocean observatory concept). For the mobile entities, data collection runs gather *in situ* samples, casts, or tows of various types for future laboratory analysis. These may be made at predefined sites or along predefined transects or tracklines. For fixed entities, raw datasets are sent back to shore from the hydrophones or moorings for decryption and processing. Marine surveys from these mobile and fixed entities are often made at points in space and time and may have multiple assessments of the geophysical, geological, chemical, physical, and biological properties of the marine environment. Each of these different kinds of ocean observations may also have one-to-many assessments of data quality or error.

## Featured case studies

Surveys are made for a variety of purposes. Two purposes described in this chapter are the mapping of the seafloor along the inner continental shelf of Massachusetts to understand regional geology, ultimately for subsequent biological sampling and benthic habitat mapping (where and how big are the environmental impacts to the health of fisheries?), and for subsurface seismic surveying and coring of the seafloor off Louisiana to test theories about subsidence and rise of the sea level.

Brian Andrews, a researcher at the USGS Woods Hole Science Center for Coastal and Marine Geology, implemented the Massachusetts case study in cooperation with colleagues at the Massachusetts Office of Coastal Zone Management. High-resolution swath bathymetry, sidescan sonar imagery, and seismic-reflection profiles were collected at depths of 5 to 40 m in a survey area of 134 km<sup>2</sup> encompassing a portion of the South Essex Ocean Sanctuary between Gloucester and Nahant, Massachusetts (Andrews 2005; Barnhardt et al. 2005; figure 3.1). In addition, 100 ground-truth stations were established where bottom videos, photographic stills, and sediment grabs were collected. These represent typical geological and geophysical data collected by the Woods Hole Science Center on a regular basis throughout the New England inner continental shelf (figure 3.2). The South Essex surveys aimed to understand the geological and geophysical framework of the region to classify the seafloor into bottom types (e.g., gravel, sand, sandy silt, silty sand, cobble/boulder province), and ultimately into benthic habitat classes associated with fish species (heeding the caveats of studies such as Greene et al. 2005). A long-term goal of the study is to support the marine resource managers charged with making decisions about the use and protection of resources in South Essex, a marine-protected area. The geologic mapping is a first step toward identifying and protecting fish habitat, understanding the location and size of environmental impacts on the health of these habitats, and delineating new marine reserves as a result. From a data management standpoint, an additional question was how to synthesize the main kinds of survey data collected at sea to be the most effective at interpreting the data (in this case, interpreting the surficial geology) through subsequent analysis and map production (Andrews and Ackerman 2004). Arc Marine presented a viable solution.

Heather Mounts, senior database developer at Photo Science, Inc., (PSI) in St. Petersburg, Florida, implemented the Louisiana case study in cooperation with the USGS Florida Integrated Science Center for Coastal and Watershed Studies. Coastal geologists at the center teamed with geologists and geophysicists at the U.S. Army Corps of Engineers and the University of New Orleans to gather data on subsidence and sea-level rise within the Mississippi River delta plain and out onto the Louisiana continental shelf (figure 3.3). The devastating effects of Hurricane Katrina in August 2005 illustrate the ongoing importance of this collaborative study. The Mississippi River delta plain is subject to the highest rate of relative sea-level rise (3 feet per century) of any region in the United States, due largely to reduced sediment supply and rapid geologic subsidence and also to global atmospheric warming (Kindinger 2000). This translates to 40 sq. mi. of wetland deterioration and marshland loss per year (also the highest in the United States; Wilson and Gesch 2004) and increased potential for flooding and heightened storm impact. Subsidence and

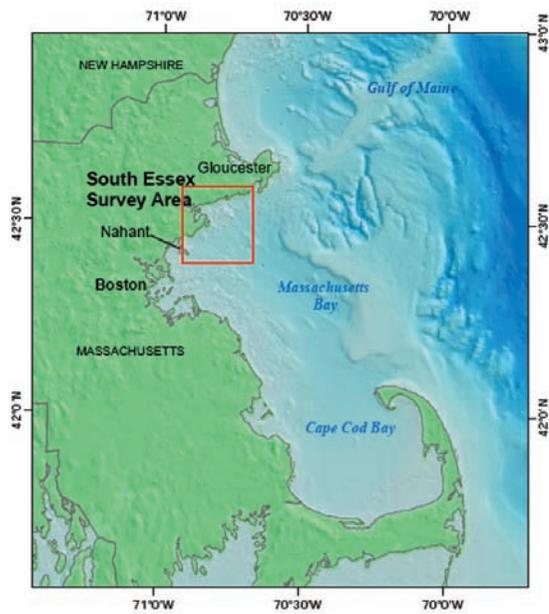


Figure 3.1 Location map of South Essex survey area, Massachusetts case study.

Courtesy of the U.S. Geological Survey.

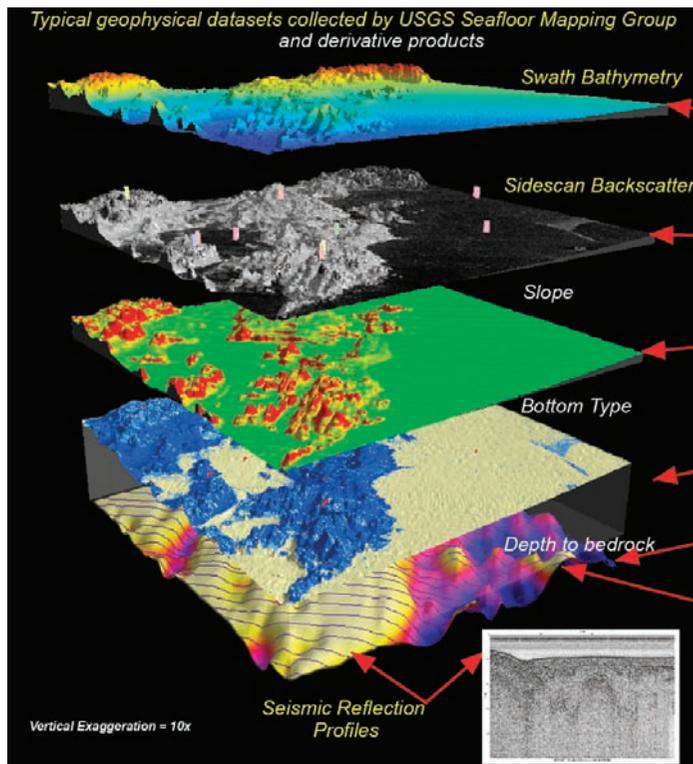
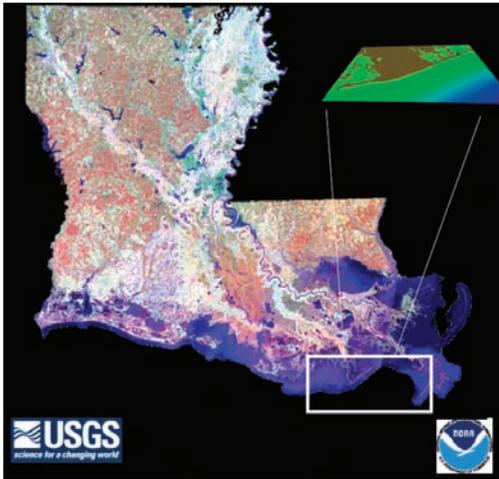


Figure 3.2 Typical datasets collected by the USGS Seafloor Mapping Group of the Woods Hole Science Center.

Courtesy of the U.S. Geological Survey.

sea-level change are two of the most critical environmental, socioeconomic, and cultural issues facing southeastern Louisiana (Kindinger 2000). Hence the data gathered (the Louisiana Sedimentary and Environmental Database or LASED) is for the use of researchers, coastal managers, and planners.



**Figure 3.3** The white box outlines part of the study area for the Louisiana case study. All regions in southeast Louisiana surveyed by the USGS and their collaborators are not shown in this satellite image. Inset map at top right shows outline of 3D flyover of the region, available on the book's accompanying Web site, <http://dusk.geo.orst.edu/djl/arcgis/>.

Courtesy of Robby Wilson, NOAA.

Datasets needed to understand the nature and extent of geologic processes in the region have included sediment cores, seismic-reflection profiles, bathymetry, and sidescan sonar collected on several cruises and associated tide gauge data, carbon-14 dating of sediments, and satellite imagery. In 2003, the USGS enlisted PSI to incorporate the cruise logistics information and the seismic and sediment core data into an ArcGIS geodatabase. PSI built the geodatabase based on Arc Marine, choosing also to incorporate database schemas from usSEABED (a suite of software for integration of marine substrate data; Reid et al. 2001; Jenkins 2004) and the Oracle-based Florida Reconnaissance Offshore Sand Search Database (Niedoroda et al. 2004). The result has been an efficient query and retrieval mechanism for the large amount of cruise, trackline, core, and seismic data, along with other information regarding the Louisiana subsidence project. Users also can view or download core photos, core logs, interactive HTML seismic profiles, and core documents related to their query. PDF versions of these documents and image files were hyperlinked to the various feature classes.

In the parlance of Arc Marine, a ship goes out on an expedition (or cruise) of several days to weeks in duration. Within that cruise, multiple smaller trips are taken, commonly referred to as surveys. Either within a cruise or within several surveys, many specific tracks are taken (figures 3.4 and 3.5). And along a track, many point locations may be recorded with multiple variables measured at varying depths over time (figure 3.5). The following sections describe the most important feature classes and object tables in Arc Marine with regard to marine surveys, illustrating also how they were implemented in real projects by the featured case studies.

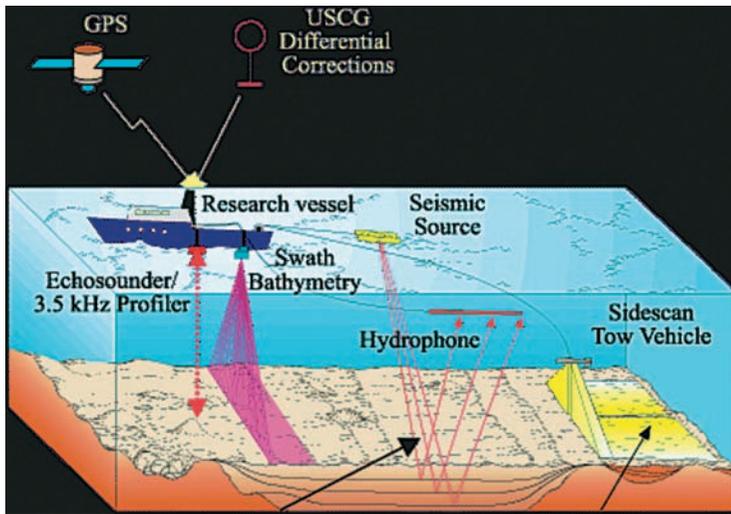


Figure 3.4 Graphic showing various survey methods and instruments at sea, including swath bathymetry, sidescan sonar, and seismic profiling.

Courtesy of the U.S. Geological Survey.

## Common Marine Data Types

### Marine Points

#### Instantaneous Points

Instant Subtype
ID
X,Y
Z or $\Delta Z$
$m_1...m_2$
$t$
<b>Examples:</b> CTD, XBT, SVP casts at $\Delta Z$ , fish density, tide gauge, etc., at surface or a single Z

### Marine Lines

Profile Line
ID
X,Y
$M_1, M_2$
$Z_1, Z_2...$
<b>Examples:</b> for abstracting data from, building profile from, measuring change along... seismic reflection, bathy profile, cross section, sed. transport line

Time Duration Line Track
ID
$X_1, Y_1, X_2, Y_2...$
$M_1, M_2$
$Z_1, Z_2...$
$m_1, m_2...$
$t_1, t_2...$
<b>Examples:</b> transit ship track, ROV or sub track, algal bloom trawl, ADCP tracks, ARGO drifter

Figure 3.5 Common Marine Data Types (from chapter 2) featured in the Massachusetts and Louisiana case studies. Headings in italics are abstract feature classes in Arc Marine. All other headings are feature classes or subtypes of feature classes.

## Marine features

The superclass of Arc Marine is referred to as `MarineFeature`. This being a hierarchical model, all other feature classes inherit from this superclass. The `MarineFeature` class introduces two attributes, `FeatureID` and `FeatureCode`. Adding these attributes to this superclass ensures that they are present in all features. `FeatureID` is an integer field designed to be a unique identifier throughout the geodatabase. `FeatureID` acts as a key field for many of the relationships built into the data model. The `FeatureID` should be used as the key field if additional relationships involving feature classes are necessary. `FeatureCode` is a string field that provides a way for users to include alpha and numerical information in the identifier. If features in a feature class do not have their own code, then the user should just ignore this field. Both fields are populated by the user, as there is no tool in Arc Marine for automatically generating these values.

Under the superclass `MarineFeature`, three abstract classes organize the data model into feature data types. An abstract class represents an abstract concept and is never instantiated, meaning that instances of this class are not created and never appear in a geodatabase. These abstract classes are `MarinePoint`, `MarineLine`, and `MarineArea`. Each of these classes or groups of features is explained in detail throughout the book. This chapter will concentrate primarily on `MarinePoint` and its subclasses.

## Point features

The class `MarinePoint` is further divided into two thematic subclasses, `FeaturePoint` and `MeasurementPoint`. `FeaturePoint` is a simple feature class for storing permanent geographic features whose spatial representation can be described with a single pair of x- and y-coordinates (e.g., a navigational buoy). This feature class adds no additional attributes and can easily be instantiated or can become a parent class from which a subclass is added. If a subclass is inserted and inherits from the `FeaturePoint` class, then `FeaturePoint` should be converted to an abstract class. In this way, only the user-defined subclass is instantiated and appears in the geodatabase. Unless `FeaturePoint` or other superclasses are made abstract, users will end up with unwanted feature classes in their geodatabase.

Recording varying measurements in a point feature is one of the more complex concepts of the Arc Marine data model, providing a variety of phenomena for the data model to solve. `MeasurementPoint` is designed to be a thematic organization for all points where measurements are taken. As an abstract class, it will never appear in a geodatabase as a feature class. Rather, two feature classes inherit from it, `TimeSeriesPoint` and `InstantaneousPoint`. However, the `MeasurementPoint` class adds one attribute, `CruiseID`, which is a key field and provides the framework for constructing a relationship class between the two subclasses (relationship classes between classes that have dependent classes are not permitted, so `MeasurementPoint` can never participate in a relationship) and the `Cruise` object class.

TimeSeriesPoint is designed as a feature class that represents point features in which time series data would be associated. For example, a moored buoy would have devices attached for measuring wave height or temperature at intervals during a long time period. The measured values of wave height or temperature would constitute the time series (please refer to chapter 5 for more information regarding time series data), and the moored buoy would be represented as a feature (instance) of the TimeSeriesPoint feature class. The TimeSeriesPoint class adds no additional attributes.

InstantaneousPoint is a feature class for storing all other point features where measurements are taken. This feature class has four subtypes (an attribute in the feature class to categorically distinguish one point from another): Instant, Sounding, Survey, and LocationSeries. This chapter describes the Survey subtype. For information on the other subtypes, please refer to chapters 4 through 6.

InstantaneousPoint is defined as a point feature that is fixed in space and time, meaning that a unique feature (and a new value for FeatureID) is defined by its x,y coordinate pair (shape) plus a single time stamp. In theory then, one InstantaneousPoint at location 669325.68, 6056605.93 with a time stamp of 24.03.1964 18:00:00 is a unique feature. A feature at the same location but with a time stamp of 24.03.1964 18:30:00 would also be a unique feature. Furthermore, two points with different x,y coordinates but with the same time stamp would be considered two unique features. The InstantaneousPoint feature class adds several additional attributes. The ZValue attribute is for storing a single depth, perhaps the sea surface or the seafloor, of the feature. However, the following section describes how point features can have multiple depths associated with them by implementing the Measurement object class. The SeriesID attribute is used as a key field for constructing a relationship class between this feature class and the Series object class. In this way, many points can belong to the same series. A series is yet another means of grouping a subset of points into a thematic organization. This is well illustrated in chapter 4. SurveyID is another key field used in the relationship class SurveyInfoHasPoints, in which zero to many points can be collected into a single survey and then defined by a single entry in the SurveyInfo table. Lastly, the PointType attribute is the subtype field in place to determine the subtype of the point. The default value for this field is 1, which identifies Instant as being the type for the point.

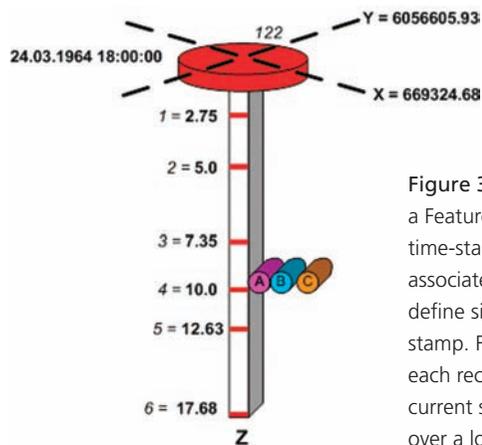
## Measurements and virtual features

One of the greatest design challenges for Arc Marine, and specifically for point features, was developing a schema that could emulate the complex and variable ways of sampling and observing the marine environment. At each depth, there could be a variety of measuring devices, with each device recording one or more variables. Additionally, the single feature and all of the measurements recorded at each of the depths could be tagged with the same time stamp, or each measuring device could be recording different variables during an extended time period.

Measuring locations below the surface of the sea can be modeled in Arc Marine with the use of additional object classes. The Measurement object class (a table in Arc Marine) is used for storing information about the multiple depths of a feature, and the MeasuredData object class (table) can store the various values being recorded. Figure 3.6 shows the example of an InstantaneousPoint with FeatureID = 122. Six depths are associated with this point. The numbers 1 through 6 identify the Measurement. At Measurement 4, there are three measuring devices, A, B, and C. Each of these could be recording one or more variables either at a given time step or over a long time period. The values measured at a single time step might be stored in the MeasuredData table, whereas the values being recorded during a long period would be stored as a time series using the TimeSeries object classes. See chapter 5 for details on the specifics of using the TimeSeries object classes.

This phenomenon could be represented in a database by designing a schema in which each combination of x-, y-, and z-coordinates represents a unique feature. With this schema, users end up with multiple features, essentially representing the same phenomenon stacked on top of one another. From a data management perspective this schema may be difficult to manage, even though it provides some benefits from a functionality perspective. Furthermore, given the potential quantity of data being collected, having to store and replicate the x,y coordinate pairs for the same feature (one pair of coordinates for each depth) can occupy vast amounts of disk space. Granted, having multiple points at various depths and essentially representing measurements within the water column lend themselves easily to many GIS applications. However, as a means of storing data, this schema is neither efficient nor practical due to the vast amounts of replicated data. Application developers are encouraged to use the data storage mechanism of this data model and rely on software applications to stack the points at their respective depths within the water column.

With the Arc Marine schema, this phenomenon can be replicated in two ways. Both rely on the Measurement table as an intermediate table for storing the multiple depths associated with a given point feature. The outcome of this table is referred to as a “virtual feature.” The Measurement table has six attributes. The first four, MeasurementID, FeatureID, FeatureClass, and ZLocation, help define the virtual feature. The other two



**Figure 3.6** A feature in the InstantaneousPoint feature class, with a FeatureID of 122, is uniquely identified by its x,y coordinates and time-stamp properties. For that point, a given number of depths can be associated, each receiving a unique identifier. In this case, 1 through 6 define six virtual features, all having the same values for x, y, and time stamp. For each depth, one or more measuring devices exist (A, B, C), each recording one or more variables (e.g., salinity, current direction, or current speed), either at the single time step identified by the point or over a longer period.

attributes, XLocation and YLocation, assist in qualifying drift that may be introduced at a given depth. MeasurementID is meant to be a user-assigned unique identifier in this table. FeatureID is a key field used for building relationships with the FeatureID of the feature class. The value of this field should replicate the FeatureID value from the Point feature class. The FeatureClass attribute stores the name of the feature class in which the feature resides. This attribute is added to help the application developer search for a given feature by its FeatureID. It's easier to search for the matching feature with the same FeatureID if it's known in which feature class it exists. The ZLocation attribute is the below-surface-depth value associated with the feature.

The key to implementing this table (figure 3.7) correctly is that the MeasurementID remains unique. In the Measurement table, the unique combination of the FeatureID of a point and a ZLocation (depth) creates a new record in the table. A unique value for MeasurementID should be assigned to that record. The MeasurementID attribute then becomes the identifier of the "virtual feature." In the Measurements table, the FeatureID would be repeated for each depth associated with a single feature. If Feature 122 has six depths associated with it, then a value of 122 would be repeated six times for the FeatureID attribute. For each record added, the ZLocation value should change and the value of the MeasurementID should be unique.

To further the Arc Marine solution to this phenomenon, the MeasurementID is carried over to the MeasuredData table. In that table, the MeasurementID is a key field that

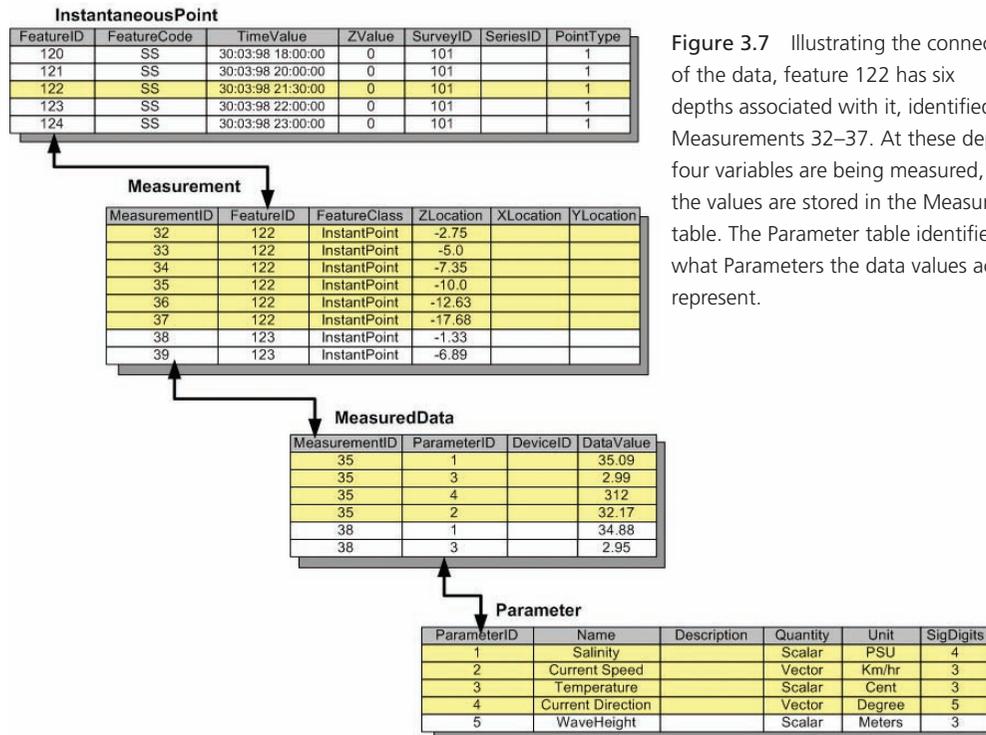


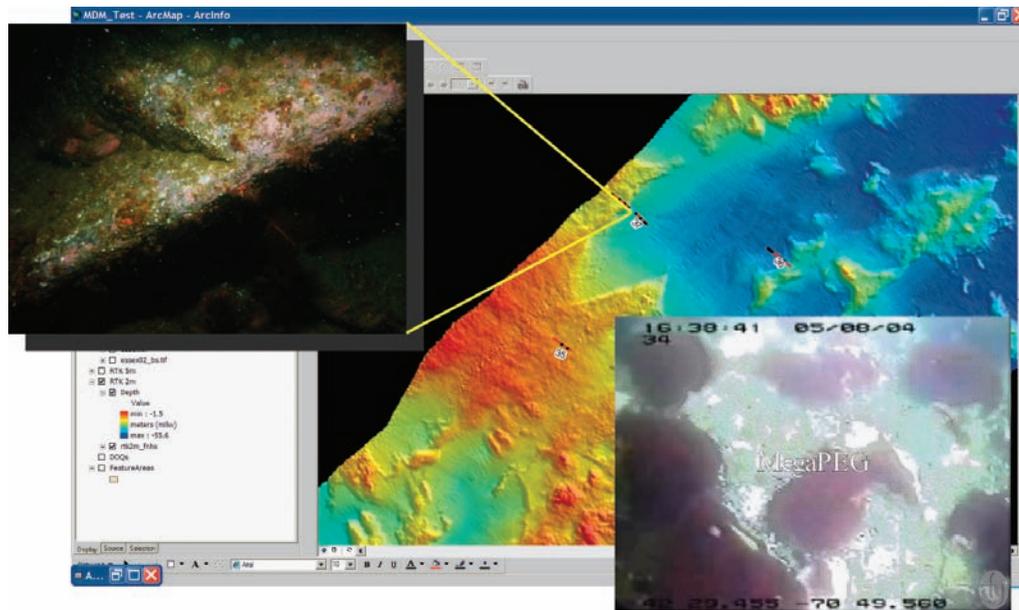
Figure 3.7 Illustrating the connectivity of the data, feature 122 has six depths associated with it, identified as Measurements 32–37. At these depths, four variables are being measured, and the values are stored in the MeasuredData table. The Parameter table identifies what Parameters the data values actually represent.

can be repeated for each parameter being measured. This is accomplished through the MeasurementHasData relationship class, which allows a single measurement to have zero or many entries in the MeasuredData table. So, in reference to the two previous graphics, the depth of -10 for feature 122 is assigned a MeasurementID of 35, which happens to have three measuring devices, A, B, and C. For the sake of explanation, we'll say that measuring device A measures temperature, measuring device B measures salinity, and measuring device C measures current speed and direction. Consequently, in the MeasuredData table, MeasurementID 35 is repeated four times, once for each of the parameters being measured at that depth.

The Massachusetts case study by Brian Andrews is one excellent example of Arc Marine implementation. Andrews is conducting a marine geophysical survey with three concurrent acoustic measuring devices: interferometric sonar for bathymetry and backscatter, side-scan sonar for backscatter, and seismic-reflection profiling for sediment stratigraphy and structure (figure 3.4; for more details and definitions, see Barnhardt et al. 2005). The survey vessel collects data with these three sonars along predefined survey lines 100 meters apart. These lines are represented in the USGS version of the data model by a feature class called SurveyLine, an additional subclass of the ProfileLine feature class developed by Andrews. Along this SurveyLine, a swath of points is collected for bathymetry and backscatter perpendicular to the track of the ship (figure 3.4), and each swath is marked with a time stamp. Also along this survey line, seismic shot points are taken from hydrophones trailed behind the ship, and each shot point is marked with a time stamp (figures 3.4 and 3.10), which easily make the InstantaneousPoint the appropriate feature class for storing this data. At the completion of the geophysical portion of the project, the acoustic remote sensing data is "ground validated" with towed video, bottom photographs, and sediment samples (also known as "bottom grabs") (figure 3.8). The points where the bottom photos and the sediment samples are being taken are time stamped and also fit into the InstantaneousPoints feature class. However, each of these three point types represents different features with different attributes and different uses. Consequently, the data model that Andrews is implementing requires that InstantaneousPoint is made an abstract class and three new feature classes are added: SeismicShots, BottomPhotos, and SedGrabs. Each of these new classes inherits properties from InstantaneousPoint and has its own set of attributes.

Andrews then adds a SurveyLineID attribute to each of the three point feature classes that acts as a key field. It is populated with the FeatureID of the SurveyLine along which the point was recorded. He creates three new corresponding relationship classes that allow for one-to-many relationships between a SurveyLine and the three point feature classes. With this structure, Andrews can track which points are associated with which SurveyLines (figure 3.9). He will also add the SurveyID to the SurveyLine feature class and build a relationship between this feature class and the SurveyInfo table. From this, he can manage which points belong to a specific SurveyLine feature and to which Survey the SurveyLine belongs. He also can identify which of the SurveyLine features are associated with a given measuring device.

The BottomPhotos and the SedimentGrabs feature classes each have only a single depth associated with them and will use the ZValue attribute inherited from InstantaneousPoint to store that value. However, the SeismicShots could have any number of depths associated



**Figure 3.8** Bottom grab locations (using the BottomPhotos subclass of InstantaneousPoint) are overlaid on color hillshaded multibeam bathymetry in this ArcMap screen capture of the Massachusetts case study geodatabase. More than 590 bottom photos and 60 MPEG movies are hyperlinked to these points in the geodatabase.

Courtesy of the U.S. Geological Survey.

with them. Each depth represents a unique reflector and ultimately a unique horizon in the derived profile. These depths will be stored as Measurements, with the depth of the reflector being stored in the ZLocation attribute in the Measurement table. Additionally, Andrews has also added to the Measurements table an attribute named ReflectType that can be used to identify all of the points of a reflector type based on their classification.

Figures 3.9 and 3.10 illustrate that the SeismicShot feature with a FeatureID of 13 has four entries in the Measurement table, Measurements 1032 through 1035. Each of these Measurements is further classified according to its reflector type by use of the ReflectID attribute. Through the relationship classes that Andrews has added, he can find all of the seismic shots of a given reflector type, what survey line they are associated with, and with which survey they were recorded. He also can find all of the seismic shots along a survey line and specific reflectors within the seismic-reflection profile.

The phenomenon outlined in this chapter can be represented a second way using the TimeSeries tables. In this example, the data associated with a specific depth is a time series (a single variable being recorded over a long period at regular or irregular time steps). In the TimeSeries table, the FeatureID attribute is for storing the ID of the feature with which the specific time series should be associated. In this case, that would be the MeasurementID representing the “virtual feature” or depth of a given point feature. This case is further expanded in chapter 5.

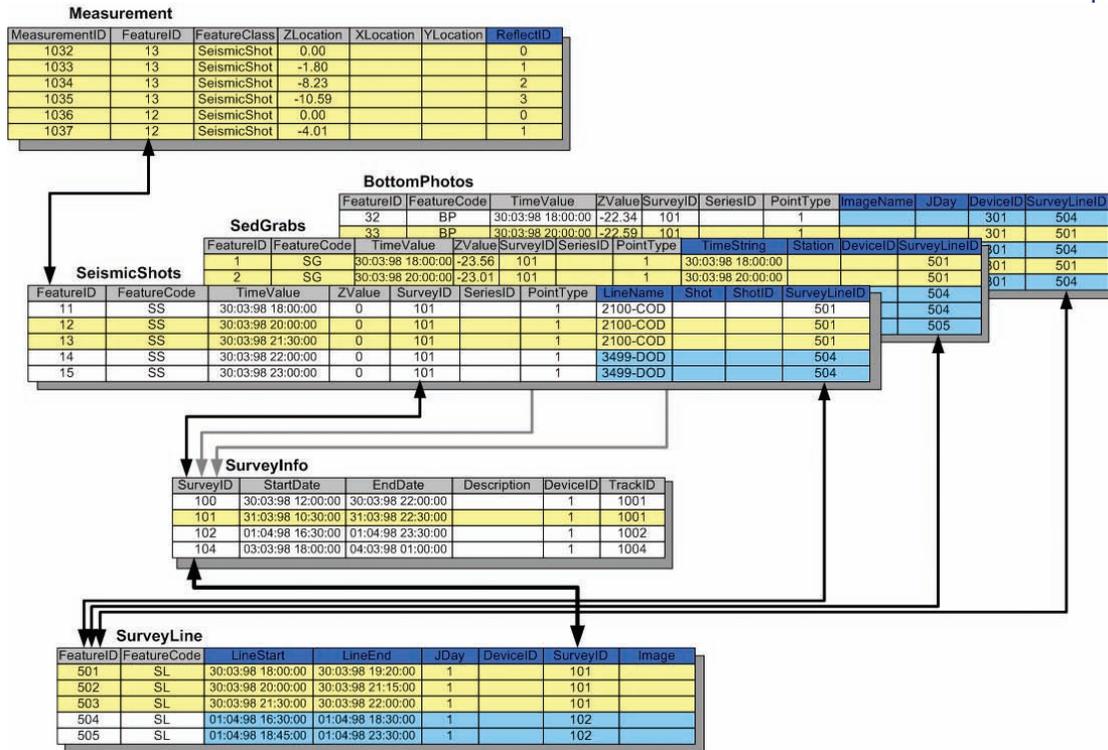
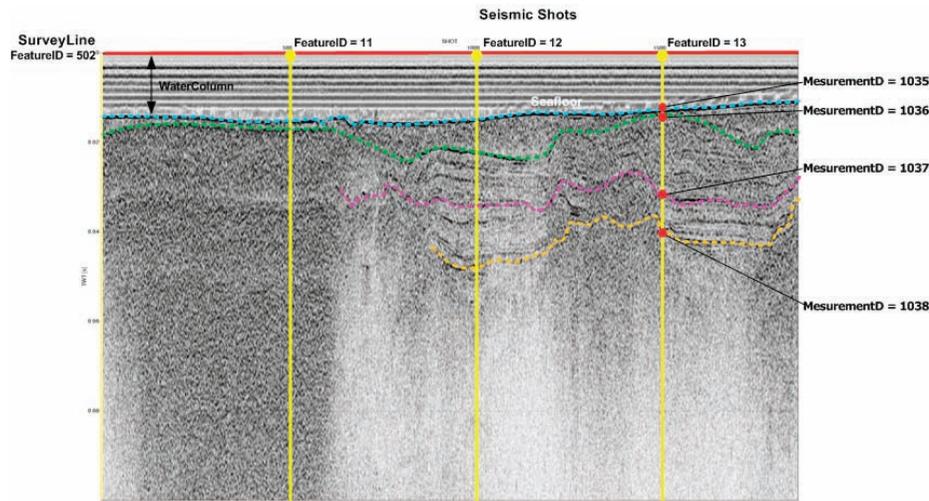


Figure 3.9 One could examine this possible data flow or connectivity for the Massachusetts case study by noting that feature 13 of the SeismicShots feature class has three associated depths, each identified as reflectors 1–3, which were collected along SurveyLine 501 and a part of Survey 101.



**Figure 3.10** An example of a typical seismic-reflection profile from the Massachusetts case study, derived from several seismic shots (with FeatureIDs of 11, 12, and 13) along one survey line. The direction of travel of the research vessel collecting the data is from left to right. Two-way travel time below the sea surface (a proxy for depth) is indicated on the left-hand y-axis. The seafloor is indicated by the aqua blue reflector. Beneath that, other reflectors are traced in green, purple, and orange, indicative of layers of sediments or basement rock below the seafloor.

Courtesy of the U.S. Geological Survey.

With this schema, the data can be approached from two different directions. By approaching the data in the direction “from a feature to a value,” a user could identify a point with several depths, drill down through those depths to select one of them, and then see any given values at that depth. Going further through the `MeasuringDeviceHasData` relationship class shows the measuring device being used to record the data values. Also from a depth, the user could go through the `ParameterHasData` relationship class and learn what parameter the value represents. Conversely, from the direction of a “parameter to a value,” a user could query the `Parameter` table for a particular variable, such as salinity. Through the `ParameterHasData` relationship class (relationship classes are bidirectional), a user could find the measured values for salinity in the `MeasuredData` table. Furthermore, at this stage the selected set could be narrowed by selecting values within a specified range. The `MeasurementHasData` relationship class can then be used to find all of the “virtual features” or depths to which salinity is associated. From the `Measurement` table, one could find the point features associated with the Measurements and render those accordingly in ArcMap software.

Using the case being developed at the USGS and illustrated in figure 3.9, Andrews can query the `SurveyInfo` table for a specific survey. From that, he can find the `SurveyLines` included in the survey and then find the point features associated with the found `SurveyLines`.

He could query SurveyInfo to show him the depths (Measurements) of the second reflector (ReflectID = 2) for the lines of a given LineName in a given survey. Or, he could ask, “Where are the SurveyLines where there is more than one reflector?”

## Surveys, cruises, and tracks

Surveys generally consist of collecting data for specific areas of interest during a cruise. Then by various means, surveys collect samples and measure values at many locations. The number of locations can range from as few as tens of values, as with soil samples or fish counts, to as many as billions of locations using multibeam swath mapping equipment capturing depth or backscatter values. However, surveys are usually a collection of points, no matter the number.

The Arc Marine data model uses the InstantaneousPoint feature class with subtype three to describe these points (e.g., figure 3.5). Information about the survey itself is not stored with the point data, because the same information would get repeated for each feature. Instead, the SurveyInfo object class stores that information. In that table, the SurveyID is used to distinguish between one survey and another. InstantaneousPoint also has a SurveyID attribute, so each point can be related to the survey in which they participate. The SurveyInfo table then becomes a collection of Surveys, and a Survey is a collection of points.

Furthermore, many Surveys can be associated with a Track feature. The Track feature class is a subclass of the TimeDurationLine feature class. These are linear features that generally have a beginning time stamp, an ending time stamp, and define the route taken during a survey. The TrackID attribute is used for identifying the unique Track feature. The TrackID attribute is also available in the SurveyInfo object class, allowing for collecting multiple surveys into a Track. However, Track also inherits attributes such as VehicleID and CruiseID from the TimeDurationLine. These attributes are added here as key fields for their respective tables, Vehicle and Cruise. In the Track feature class, additional attributes store information describing the Track, such as Name, Method, Description, and LocalDesc for describing the physical location. A Track is differentiated from a ProfileLine in that a Track may be merely a ship track, as when one leaves port to reach a survey site. Data may or may not be collected along that Track. However, a ProfileLine always involves the collection or derivation of data in a survey. The ProfileLine feature class is described in greater detail in chapter 6.

A Cruise is a row in the Cruise table, which describes the overall expedition (figure 3.11). Several basic attributes in the Cruise table describe the expedition, but many additional attributes could be added to meet the esoteric needs of specific users. An example of this is illustrated by the Louisiana case study, where it was vital to keep track of the descriptive information for several cruises launched over several years to the same regions along the southeastern coast of the United States and inner continental shelf (figure 3.12). In addition, Cruises can contain zero or many Tracks through the CruiseHasTracks relationship class, which uses the CruiseID attribute in both tables (figure 3.11).

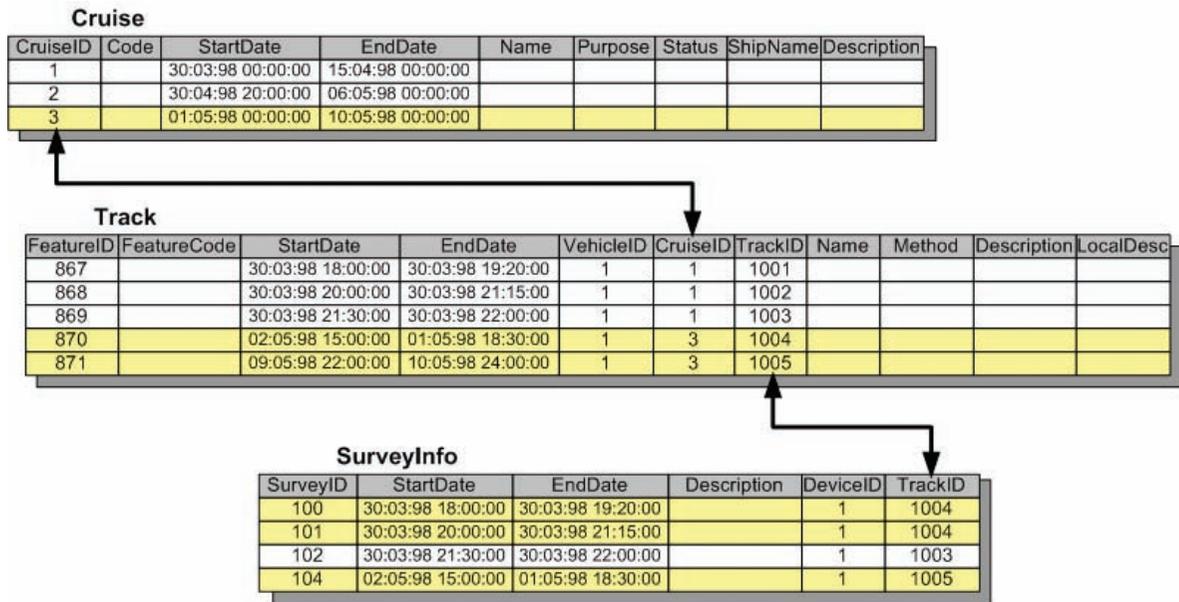


Figure 3.11 A connectivity or data flow exists between the Cruise and Track and the multiple surveys that may be conducted.

Consequently, through this data structure, a Cruise can have multiple Tracks. Each Track can have multiple Surveys. Each Survey is a collection of many points. Each point then can have multiple depths, and at each depth there might be one or more measuring devices measuring one or more variables over time. An example is a seismic line being recorded along the same positional trackline as where swath bathymetry or sidescan sonar is being collected. The three lines are spatially coincident. Yet if one device fails or a shipboard computer for a device crashes, it is still possible to collect and process data from the other two devices. Figure 3.13 from the Louisiana case study shows how a Track feature can be queried to reveal the associated Cruise information, equipment information, and shipboard science personnel responsible for collecting the data.

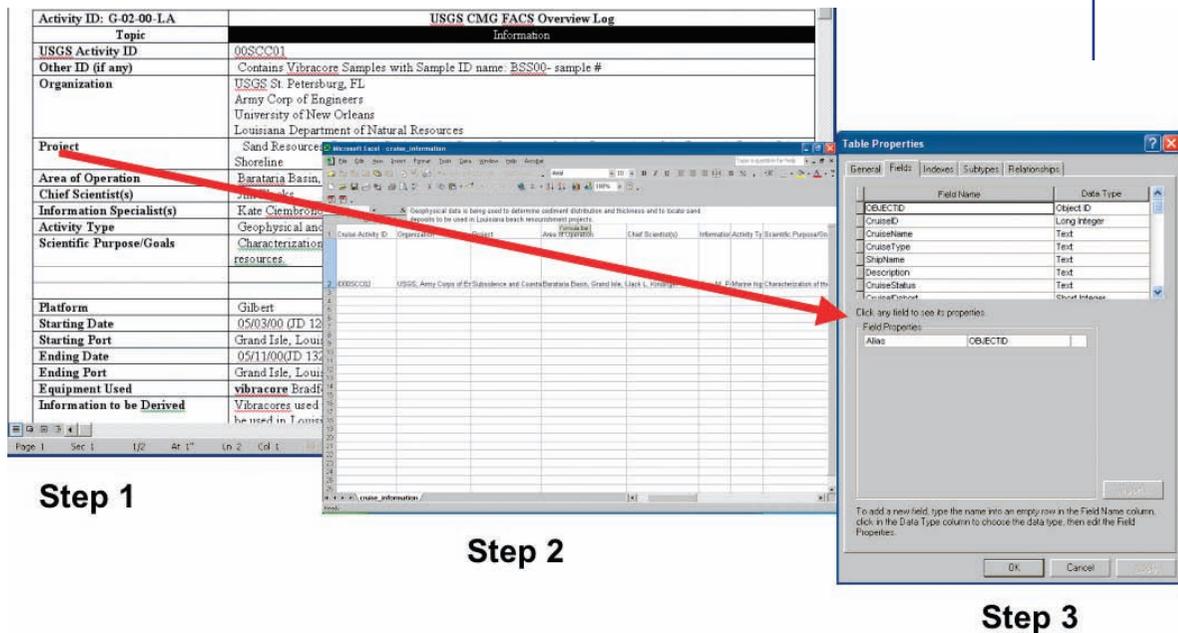


Figure 3.12 Illustration from the Louisiana case study of the transfer of descriptive cruise attributes (e.g., USGS Activity ID, chief scientist, area of operation, shipboard information specialist, ship name, ports of call, names of measuring devices used) from shipboard logs to a spreadsheet to an Arc Marine Cruise object table.

Courtesy of Photo Science, Inc.

## Measuring devices and vehicles

The DeviceID attribute in the SurveyInfo and MeasuringDevice object classes is a key field for developing a relationship class that joins surveys with a measuring device. The MeasuringDevice table describes the measuring devices. Andrews uses this capability to find the SurveyLines associated with a specific measuring device. To see SurveyLines representing the lines associated with the video ground validation, Andrews queries the SurveyInfo table for “DeviceID equal to 4.” The result of this query provides the IDs for those Surveys. Through the SurveyKey table, the specific records in the SurveyLine feature class are returned (figure 3.13).

Arc Marine provides the Vehicle object class for storing information about the vehicle being used during a survey. The table provides a VehicleID to generate relationships between this table and the MeasuringDevice table or the Track feature class.

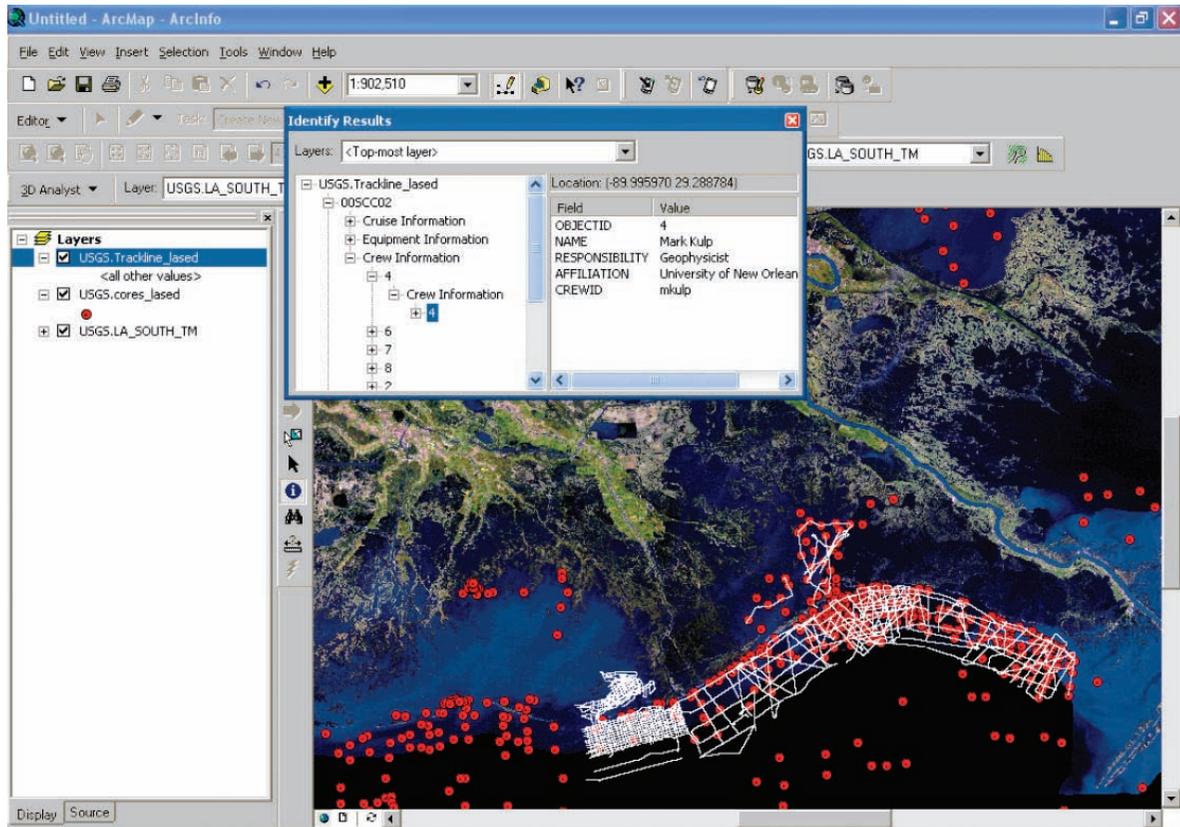


Figure 3.13 The locations of sediment cores and tracklines from several different cruises south and west of the Mississippi delta region are shown in this ArcMap screen capture from the Louisiana case study. Relationships classes from Arc Marine link cruise and track information for easier query of several different cruises. Underlay is a Landsat Thematic Mapper image.

Courtesy of Photo Science, Inc., and the U.S. Geological Survey.

## Conclusion

The previous descriptions and examples illustrate how Arc Marine can provide an excellent framework to organize, manage, query, and retrieve data from marine surveys. The Massachusetts case study showed how Arc Marine ensured the integrity of data from the planning stages of a survey and the collection of data at sea to the analysis and final publication of the data and maps. Using Arc Marine at sea at the beginning of the survey made the rest of the data collection, processing, and analysis much easier because the schema had already been defined and populated with relationships. These relationships, along with valid attribute domains and database rules (behavior), reduced errors during the data entry phase at sea and the analysis phases at sea and onshore. Existing relationship classes and database rules simplified data management throughout the project. More importantly, they facilitated geologic interpretation and modeling. Both case studies illustrate the benefits of a standardized Arc Marine schema for organizations that routinely collect, process, and analyze the same types of data, thereby facilitating collaboration across a larger network of users who can easily transport and transfer the resulting geodatabase.

The case studies were provided as examples, but there are many possible variations for other kinds of surveys (Massachusetts and Louisiana were largely geological and geophysical in nature). As mentioned in chapter 1, the Arc Marine data model is a starting point on which to build and leverage the needs and expertise of the user.

## Arc Marine class definitions featured in this chapter

FEATURE CLASSES	<b>InstantaneousPoint</b> —A point feature class representing features that are single observations in time and space. The x- and y-coordinates, plus a time stamp create the unique feature. An InstantaneousPoint can have multiple ZValues by implementing a relationship to the Measurement object class.		
	<b>Subtype</b>	Survey	
	<b>Notes</b>	InstantaneousPoint is a subclass of the superclass MeasurementPoint.	
	<b>Properties</b>	None	
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		CruiseID	A key field for relating this feature class to a Cruise
		TimeValue	The time stamp for the point
		ZValue	A single depth value for the point
		SurveyID	A foreign key to the SurveyInfo object class
		SeriesID	A key field for relating this feature to the Series table
		PointType	Defines the subtype to be one of the following: 1 = Instant (default value) 2 = Sounding 3 = Survey 4 = LocationSeries
	<b>Track</b> —A linear feature class representing the path and event associated with a specific tangent from the expedition.		
	<b>Subtype</b>	None apply	
	<b>Properties</b>	HasM = True HasZ = True	
	<b>Notes</b>	Track is a subclass of TimeDurationLine. In TimeDurationLine, the beginning of the line starts at a given time stamp and the end of the line has a different time stamp. A Track can also have a relationship with the Cruise object class via the CruiseID field. The relationship, CruiseHasTracks, is characterized by a Cruise and can have zero or many Tracks.	
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		StartDate	The beginning time stamp for the feature
		EndDate	The ending time stamp for the feature
VehicleID		A key field for relating this feature to the Vehicle table	
CruiseID		A key field for relating this feature to the Cruise table	
TrackID		An identifier for a Track feature	
Name		The name of a specific Track	
Method		Text describing the method for a specific Track	
Description		Text describing the Track	
LocalDesc	Text describing the locale of the Track		

FEATURE CLASSES (cont'd)	<b>ProfileLine</b> —A feature class representing linear features that are not physical features themselves but rather features interpolated along the line from another source—for example, a profile interpolated from a bathymetry survey.													
	<b>Subtype</b>	None apply												
	<b>Properties</b>	HasM = True HasZ = True												
	<b>Notes</b>													
	<b>Fields</b>	<table border="1"> <tr> <td>FeatureID</td> <td>A geodatabase-wide unique identifier and key field for participating in relationships</td> </tr> <tr> <td>FeatureCode</td> <td>A user-defined code used for identifying a feature</td> </tr> <tr> <td>CruiseID</td> <td>A key field for relating this feature class to a Cruise</td> </tr> </table>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships	FeatureCode	A user-defined code used for identifying a feature	CruiseID	A key field for relating this feature class to a Cruise						
FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships													
FeatureCode	A user-defined code used for identifying a feature													
CruiseID	A key field for relating this feature class to a Cruise													
OBJECT CLASSES	<b>SurveyInfo</b> —Designed for storing information about a specific survey.													
	<b>Notes</b>													
	<b>Fields</b>	<table border="1"> <tr> <td>SurveyID</td> <td>A key field for relating this table to a feature class</td> </tr> <tr> <td>StartDate</td> <td>The beginning date of the survey</td> </tr> <tr> <td>EndDate</td> <td>The ending date of the survey</td> </tr> <tr> <td>Description</td> <td>A general description of the survey</td> </tr> <tr> <td>DeviceID</td> <td>A key field for relating a survey with a Measuring device</td> </tr> <tr> <td>TrackID</td> <td>A key field for relating a survey with a Track</td> </tr> </table>	SurveyID	A key field for relating this table to a feature class	StartDate	The beginning date of the survey	EndDate	The ending date of the survey	Description	A general description of the survey	DeviceID	A key field for relating a survey with a Measuring device	TrackID	A key field for relating a survey with a Track
	SurveyID	A key field for relating this table to a feature class												
	StartDate	The beginning date of the survey												
	EndDate	The ending date of the survey												
	Description	A general description of the survey												
	DeviceID	A key field for relating a survey with a Measuring device												
	TrackID	A key field for relating a survey with a Track												
	<b>Measurement</b> —Designed for extending a single feature with multiple depths.													
	<b>Notes</b>	Measurements are designed for storing multiple depths for a single feature. This is done by creating a new and unique identifier for the feature—in this case MeasurementID—for every unique combination of FeatureID and ZLocation. In this table, FeatureID is repeated for every depth (ZLocation) associated with the feature.												
	<b>Fields</b>	<table border="1"> <tr> <td>MeasurementID</td> <td>A unique identifier for the feature created by combining unique combinations of FeatureID and ZLocation</td> </tr> <tr> <td>FeatureID</td> <td>A key field relating to the FeatureID of the feature</td> </tr> <tr> <td>FeatureClass</td> <td>The name of the feature class that the relating feature participates in</td> </tr> <tr> <td>ZLocation</td> <td>The value representing the depth being associated with the feature</td> </tr> <tr> <td>XLocation</td> <td>The x-coordinate of the feature for the given depth</td> </tr> <tr> <td>YLocation</td> <td>The y-coordinate of the feature for the given depth</td> </tr> </table>	MeasurementID	A unique identifier for the feature created by combining unique combinations of FeatureID and ZLocation	FeatureID	A key field relating to the FeatureID of the feature	FeatureClass	The name of the feature class that the relating feature participates in	ZLocation	The value representing the depth being associated with the feature	XLocation	The x-coordinate of the feature for the given depth	YLocation	The y-coordinate of the feature for the given depth
	MeasurementID	A unique identifier for the feature created by combining unique combinations of FeatureID and ZLocation												
FeatureID	A key field relating to the FeatureID of the feature													
FeatureClass	The name of the feature class that the relating feature participates in													
ZLocation	The value representing the depth being associated with the feature													
XLocation	The x-coordinate of the feature for the given depth													
YLocation	The y-coordinate of the feature for the given depth													

OBJECT CLASSES (cont'd)	<b>Cruise</b> —Stores the characteristics of a ship for the duration of an expedition.		
	<b>Notes</b>		
	<b>Fields</b>	CruiseID	An identifier for a given cruise
		Code	A user-defined code for a given cruise
		Name	The name of the cruise
		Purpose	The purpose of the cruise
		Status	Defines the status of the cruise
		Description	A general description of the cruise
		StartDate	The beginning time stamp for the cruise
		EndDate	The ending time stamp for the cruise
		ShipName	The name of the ship participating in the cruise
	<b>MeasuredData</b> —Stores recorded values for a given parameter.		
	<b>Notes</b>		
	<b>Fields</b>	MeasurementID	A key field for relating this table to the Measurement table
		ParameterID	A key field for relating this table to the Parameter table
		DeviceID	A key field for relating this table to the MeasuringDevice table
		DataValue	The recorded value
	<b>MeasuringDevice</b> —Stores information pertaining to the device taking the measurements.		
	<b>Notes</b>		
	<b>Fields</b>	DeviceID	A key field for relating this table to either another table or feature class
		Name	The name of the measuring device
		Description	A description of the measuring device
		VehicleID	A key field relating this table to the Vehicles table
	<b>Parameter</b> —Stores information about the parameters being measured.		
	<b>Notes</b> This table can be used as a mechanism for querying a geodatabase for a specific parameter and then finding values of a particular type in related tables or as a lookup table of parameter types for a particular value.		
	<b>Fields</b>	ParameterID	The unique identifier of a specific parameter
		Name	The name of a parameter
Description		The description of a parameter	
Quantity		The quantity type for a parameter. This is solved by the use of a coded value domain: 1 = Other 2 = Scalar 3 = Vector	
Unit		The unit of measure for a parameter	
Significant Digits		The number of significant digits defining the precision of this parameter	

RELATIONSHIPS	<b>CruiseHasTracks</b>	1 : *	One Cruise can have zero or many Tracks
	<b>SurveyInfoHasPoints</b>	1 : *	One Survey can have zero or many points
	<b>MeasurementHasData</b>	1 : *	One Measurement can have zero or many MeasuredData values
	<b>MeasuringDeviceHasData</b>	1 : *	One MeasuringDevice can have zero or many MeasuredData values
	<b>ParameterHasData</b>	1 : *	One Parameter can have zero or many MeasuredData values

### References

- Andrews, B. 2005. Geologic seafloor mapping using the Arc Marine Data Model. *Proceedings of the ESRI International User Conference 25*, Map Gallery Poster, [http://dusk.geo.orst.edu/djl/arcgis/docs/AdrewsUSGSPoster\\_ESRI\\_UC\\_05.pdf](http://dusk.geo.orst.edu/djl/arcgis/docs/AdrewsUSGSPoster_ESRI_UC_05.pdf).
- Andrews, B., and S. Ackerman. 2004. Geologic seafloor mapping: Marine Data Model case study. *Proceedings of the ESRI International User Conference 24*, Abstract 1877. <http://gis.esri.com/library/userconf/index.html>.
- Barnhardt, W. A., B. D. Andrews, and B. Butman. 2005. *High-resolution geologic mapping of the inner continental shelf: Nahant to Gloucester, Massachusetts*. U.S. Geological Survey Open-File Report, 2005-1293. Woods Hole, Mass.: USGS Woods Hole Science Center.
- Greene, G. H., J. J. Bizarro, J. E. Tilden, H. L. Lopez, and M. D. Erdey. 2005. The benefits and pitfalls of geographic information systems in marine benthic habitat mapping. In *Place matters: Geospatial tools for marine science, conservation and management in the Pacific Northwest*, ed. D. J. Wright and A. J. Scholz, 34–47. Corvallis, Ore.: Oregon State University Press.
- Jenkins, C. J. 2004. *Report for the U.S. Geological Survey & University of Colorado Collaboration in usSEABED-dbSEABED: 2003–4*. Boulder, Colo.: Institute for Arctic and Alpine Research (INSTAAR) Technical Report. <http://instaar.colorado.edu/~jenkinsc/dbseabed/>.
- Kindinger, J. L. 2000. *Subsidence and sea-level rise in southeast Louisiana: Implications for coastal management and restoration*. U.S. Geological Survey Open-File Report, 00–132. St. Petersburg, Fla.: USGS Center for Coastal & Watershed Studies.
- Niedoroda, A. W., L. Hatchett, and J. Donoghue. 2004. *Reconnaissance level regional sand search of the Florida Panhandle*. Tallahassee, Fla.: URS Corporation unpublished consulting report. <http://ross.urs-tally.com/reports.asp>.
- Reid, J. A., C. J. Jenkins, M. E. Field, J. V. Gardner, M. Zimmermann, C. E. Box, and T. A. Kneeshaw. 2001. usSEABED: Database efforts in marine surficial sediments of the US EEZ. *Eos, Transactions of the American Geophysical Union* 82(47), Fall Meeting Supplement: F593.
- Wilson, R. W., and D. Gesch. 2004. Merging bathymetric-topographic data to common vertical datum for Louisiana. *Proceedings of the ESRI International User Conference 24*, Abstract 2065. <http://gis.esri.com/library/userconf/index.html>.

**Case study content**

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