US 20250258309A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2025/0258309 A1
SAIT et al.
(43) Pub. Date: Aug. 14, 2025

(54) SYSTEMS AND METHODS FOR ACQUIRING SEISMIC DATA

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(21) Appl. No.: **18/441,825**

(22) Filed: **Feb. 14, 2024**

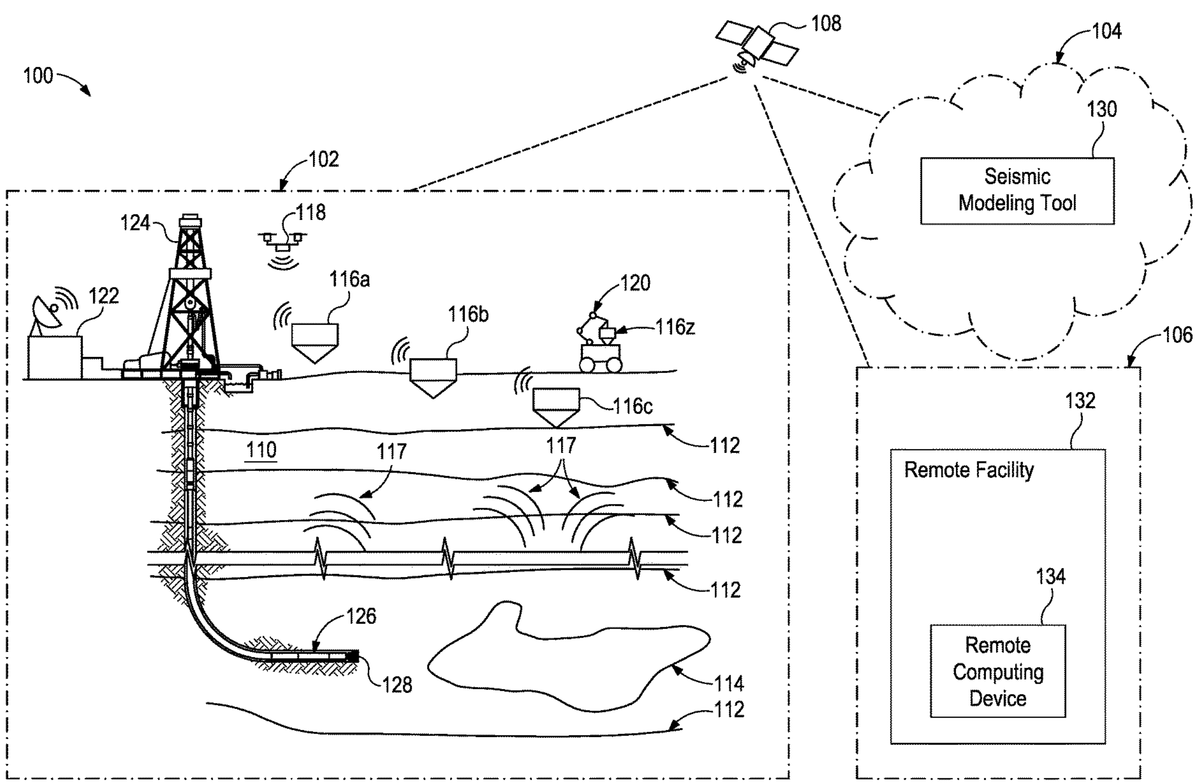
Publication Classification

(51) Int. Cl.
E21B 47/095 (2012.01)
E21B 7/06 (2006.01)
E21B 44/00 (2006.01)
E21B 47/13 (2012.01)

(52) U.S. Cl.
CPC ***G01V 1/168*** (2013.01); ***E21B 47/095*** (2020.05); ***E21B 47/14*** (2013.01); *G01V 2210/66* (2013.01)

(57) ABSTRACT

In some examples, a computer-implemented method for a self-burrowing seismic-sensing tool includes determining a course to a target destination within a subsurface formation from a surface location, operating a burrowing device to the target destination based on the course, and generating seismic data based on seismic waves received at the target destination.



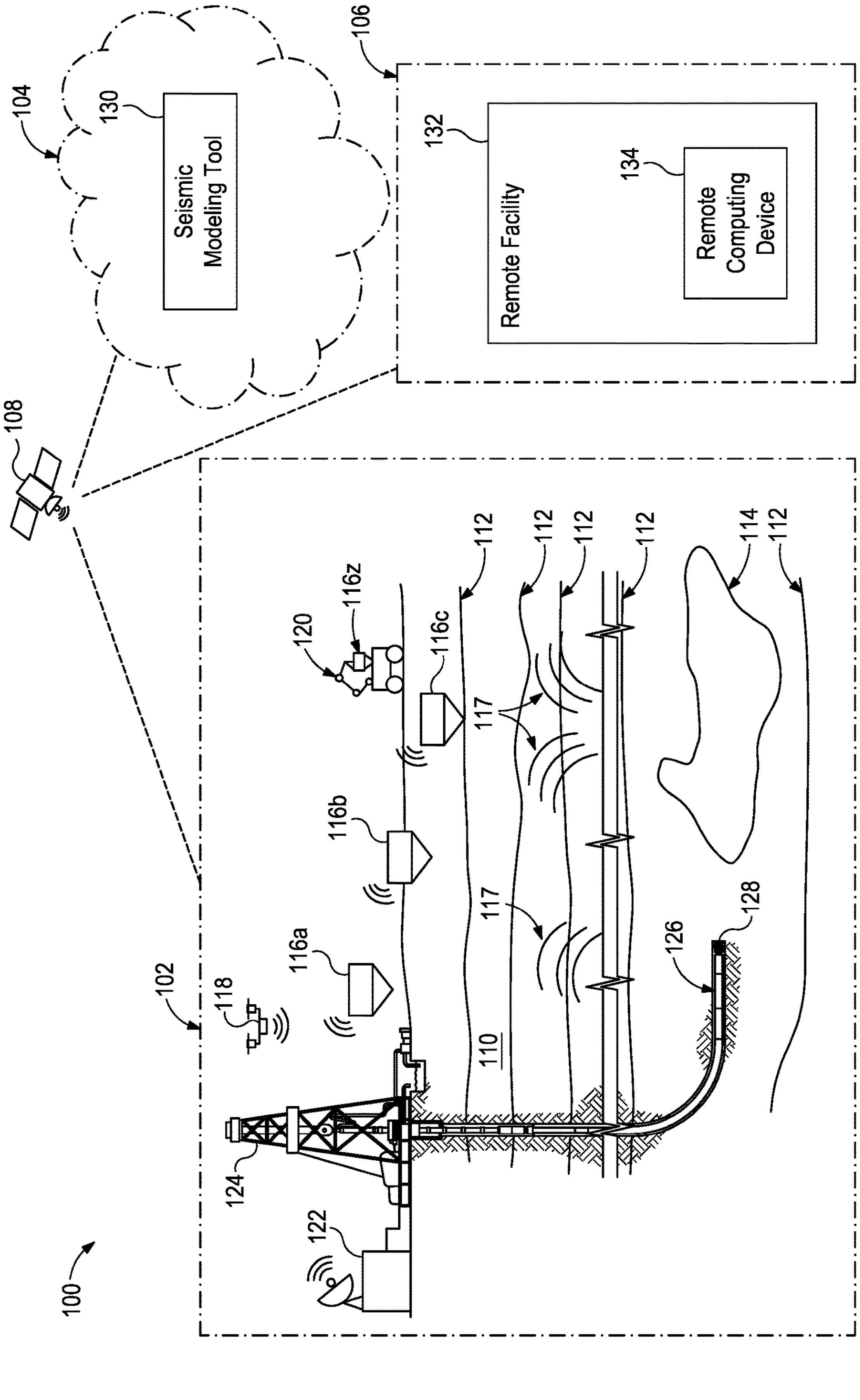

100
102
104
106
108
Seismic Modeling Tool
130
Remote Facility
132
Remote Computing Device
134
110
112
112
112
112
112
114
116a
116b
116c
116z
117
117
118
120
122
124
126
128

FIG. 1

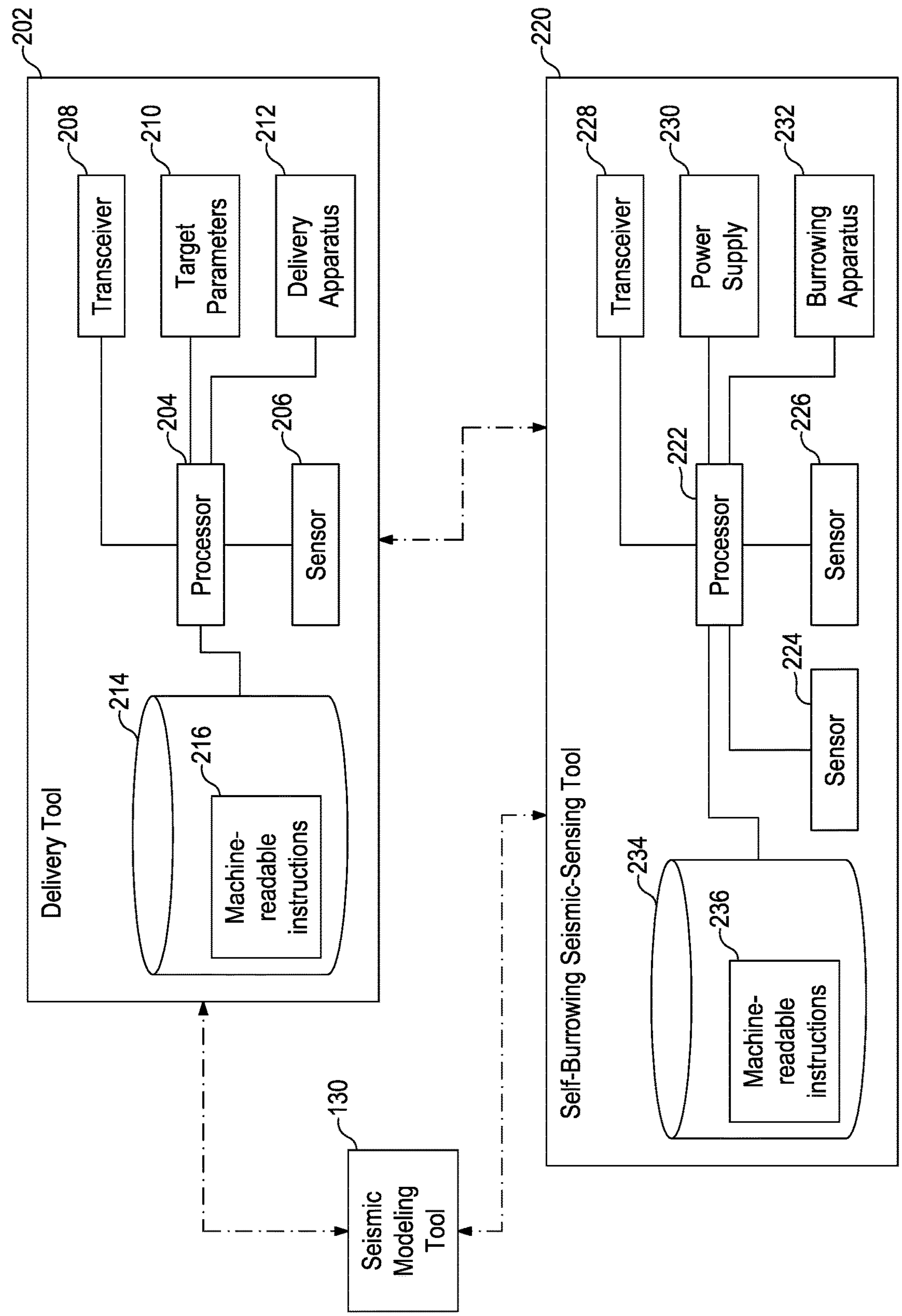

202
Delivery Tool
208
Transceiver
210
Target Parameters
212
Delivery Apparatus
204
Processor
206
Sensor
214
216
Machine-readable instructions
130
Seismic Modeling Tool
220
Self-Burrowing Seismic-Sensing Tool
228
Transceiver
230
Power Supply
232
Burrowing Apparatus
222
Processor
226
Sensor
224
Sensor
234
236
Machine-readable instructions

FIG. 2

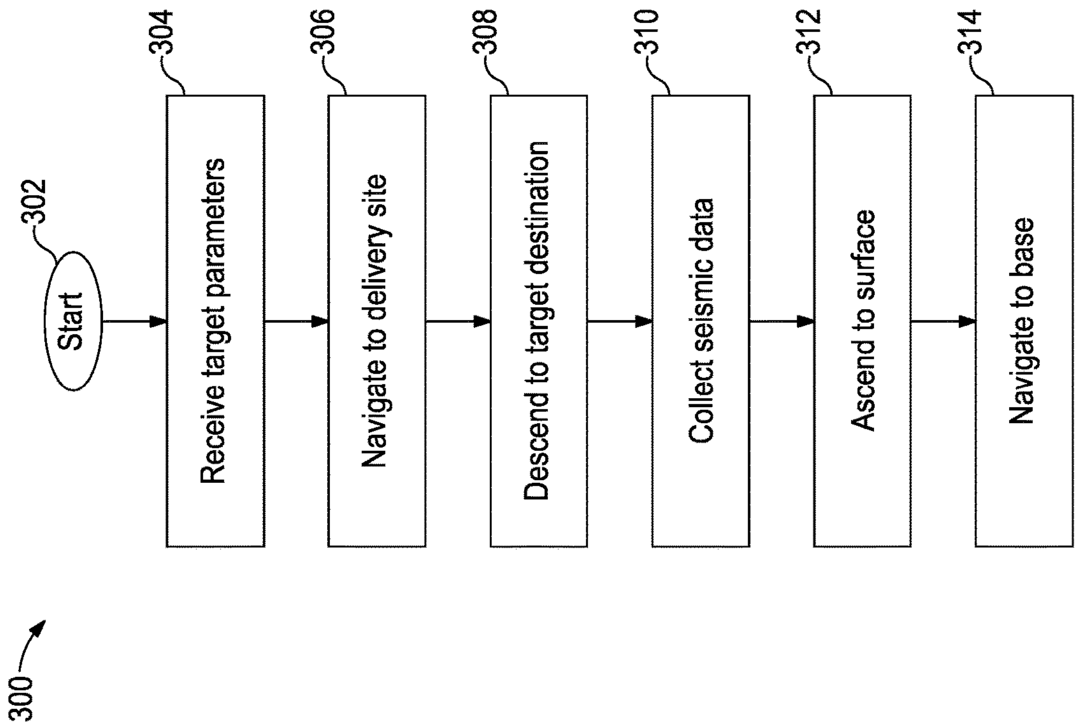

300
302
Start
304
Receive target parameters
306
Navigate to delivery site
308
Descend to target destination
310
Collect seismic data
312
Ascend to surface
314
Navigate to base

FIG. 3

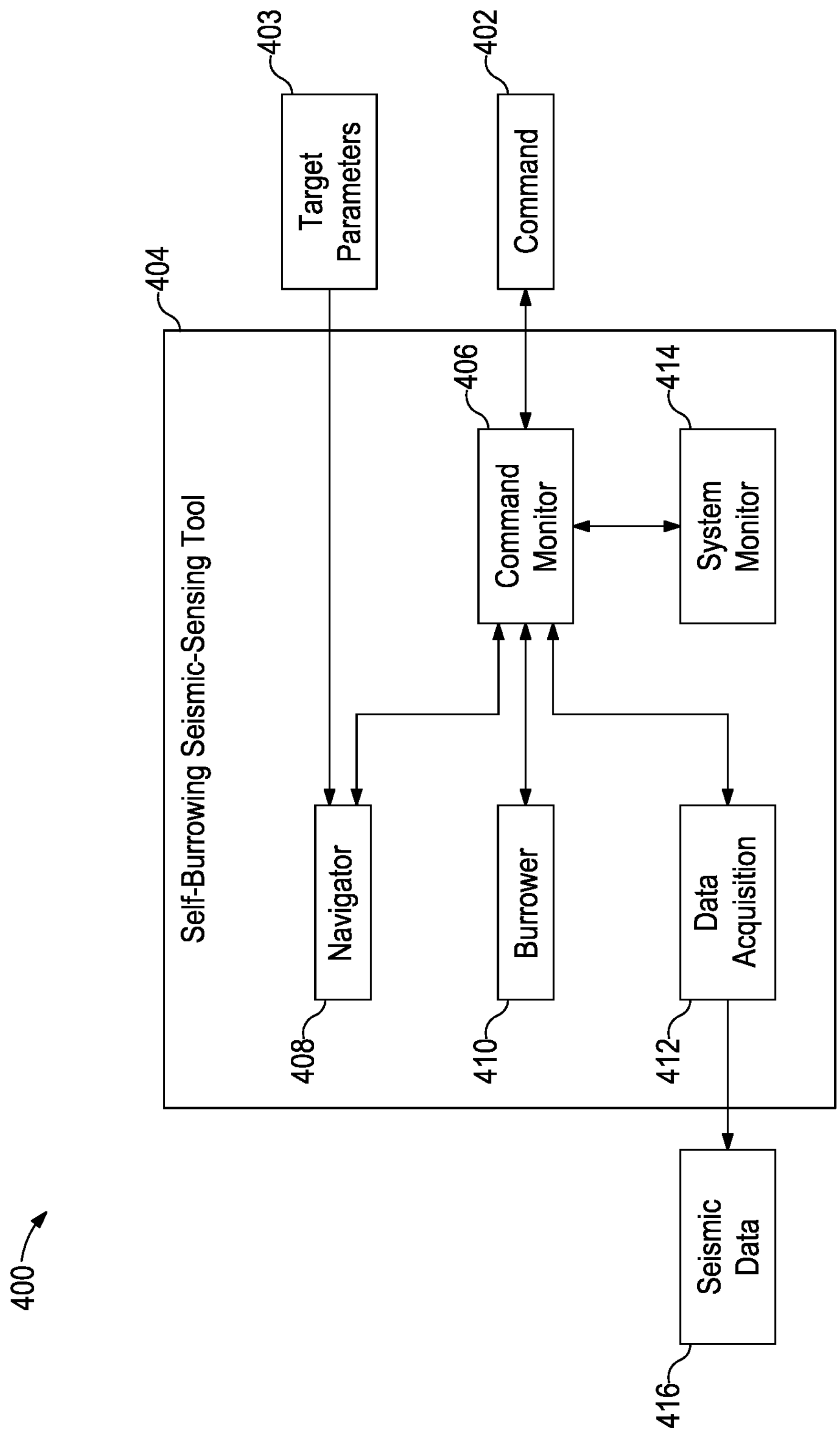

400
403
Target Parameters
402
Command
404
Self-Burrowing Seismic-Sensing Tool
406
Command Monitor
414
System Monitor
Navigator
408
Burrower
410
Data Acquisition
412
Seismic Data
416

FIG. 4

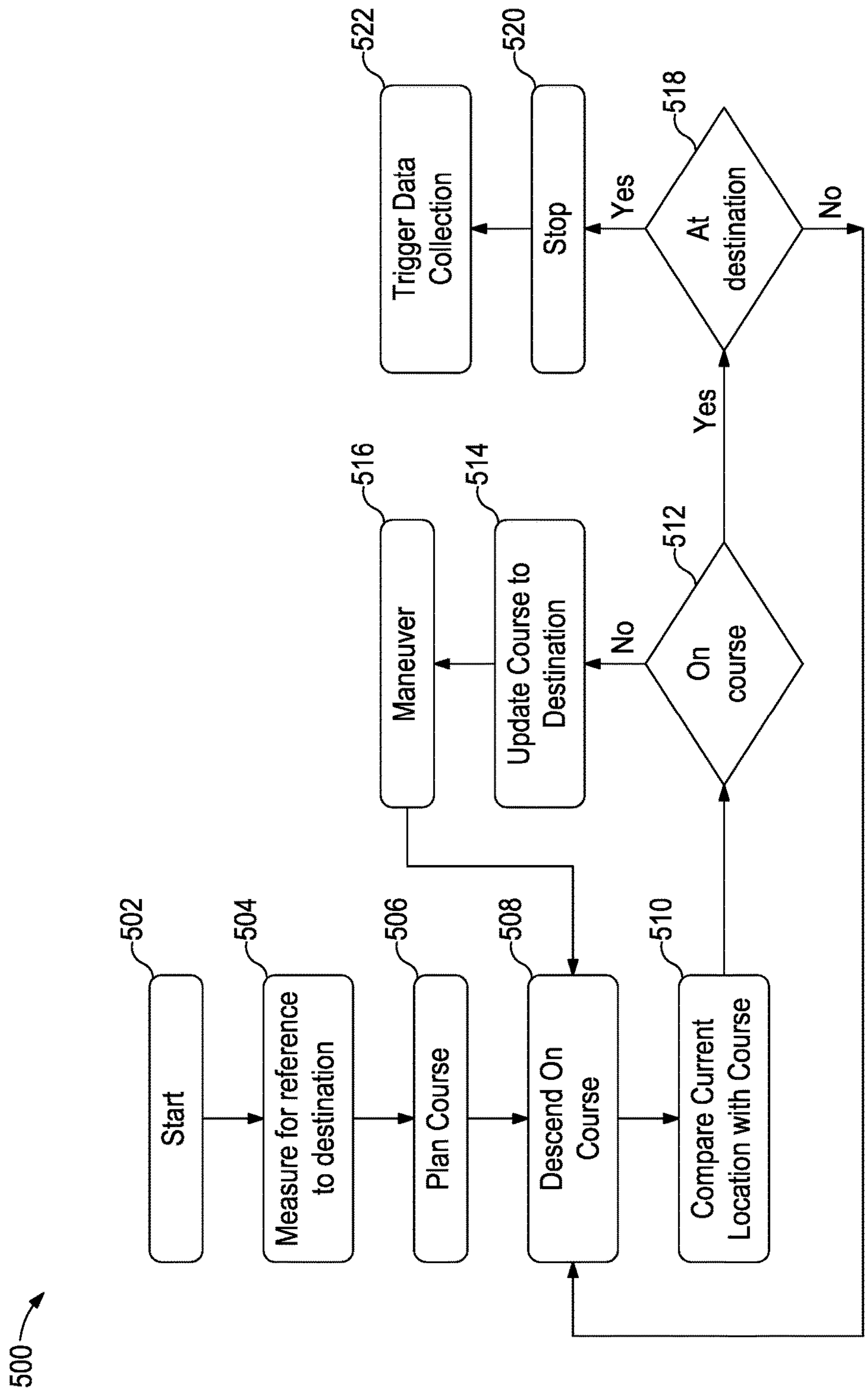

500
502
Start
504
Measure for reference to destination
506
Plan Course
508
Descend On Course
510
Compare Current Location with Course
512
On course
No
514
Update Course to Destination
516
Maneuver
Yes
518
At destination
Yes
No
520
Stop
522
Trigger Data Collection

FIG. 5

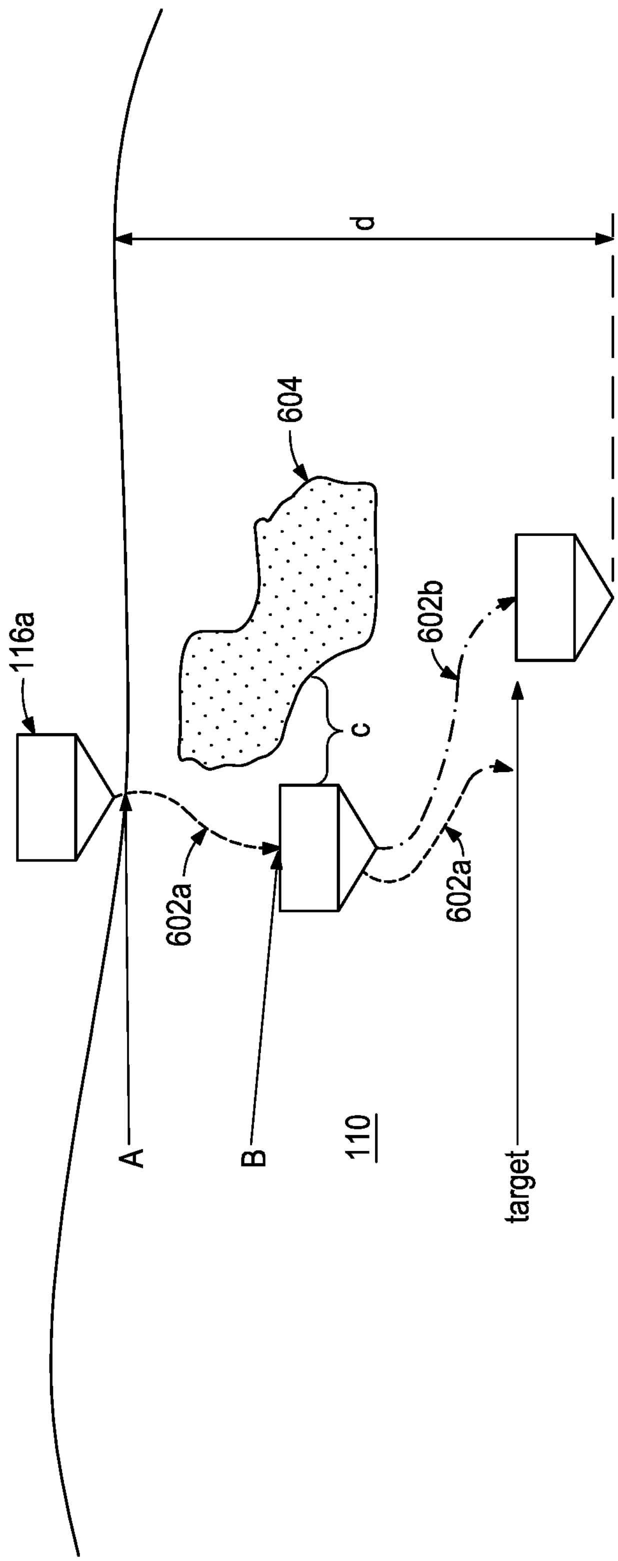


FIG. 6

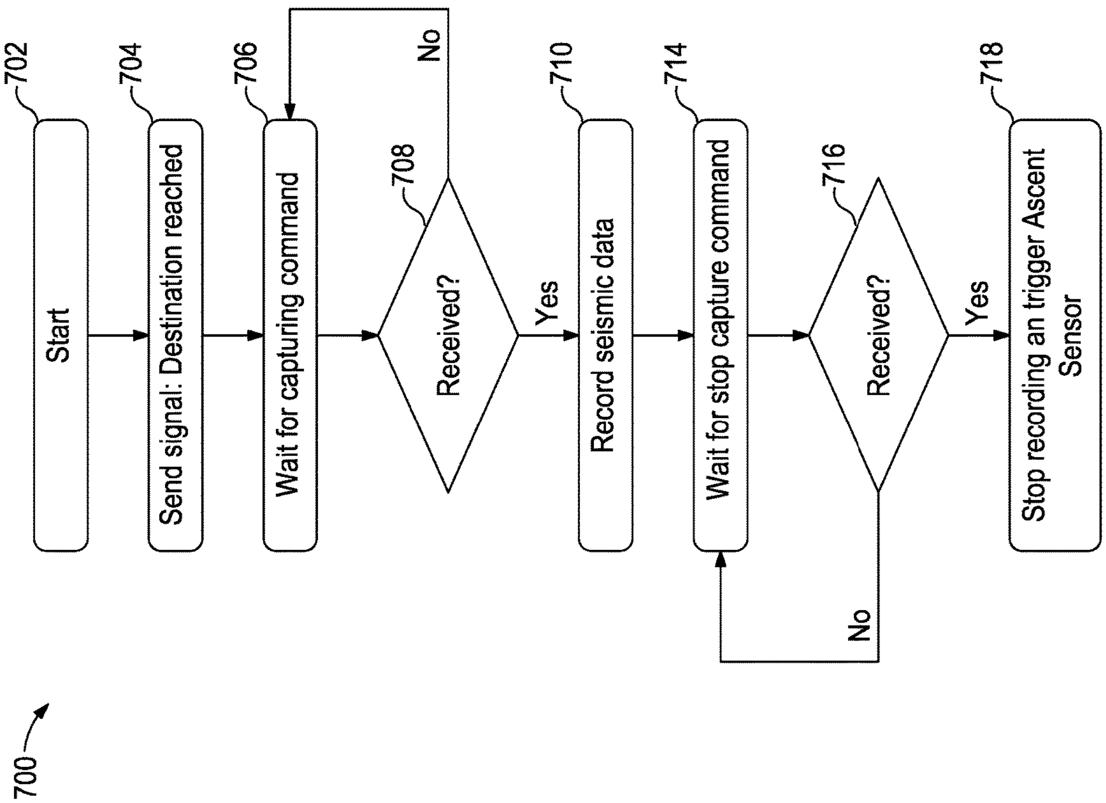

700
702
Start
704
Send signal: Destination reached
706
Wait for capturing command
708
Received?
No
Yes
710
Record seismic data
714
Wait for stop capture command
716
Received?
No
Yes
718
Stop recording an trigger Ascent Sensor

FIG. 7

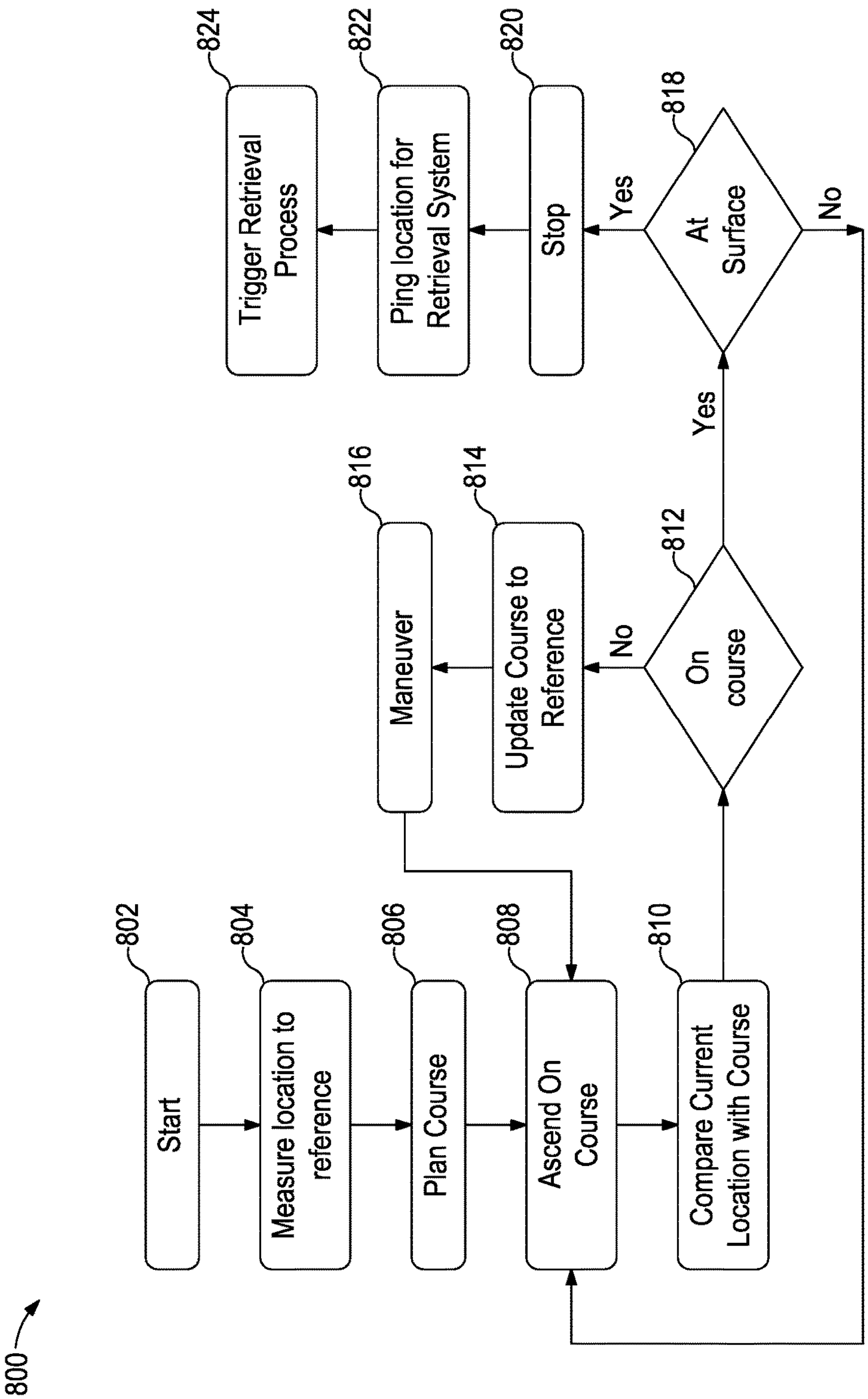

800
802
Start
804
Measure location to reference
806
Plan Course
808
Ascend On Course
810
Compare Current Location with Course
812
On course
No
Yes
814
Update Course to Reference
816
Maneuver
818
At Surface
Yes
No
820
Stop
822
Ping location for Retrieval System
824
Trigger Retrieval Process

FIG. 8

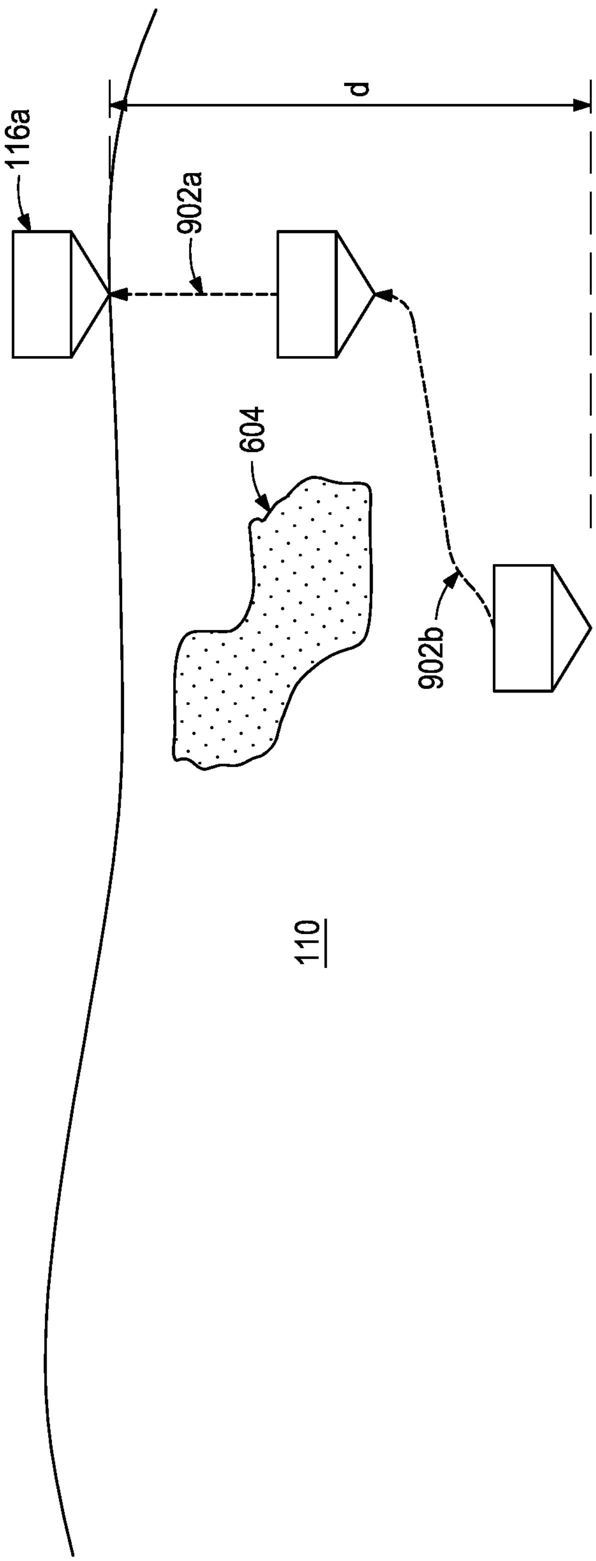


FIG. 9

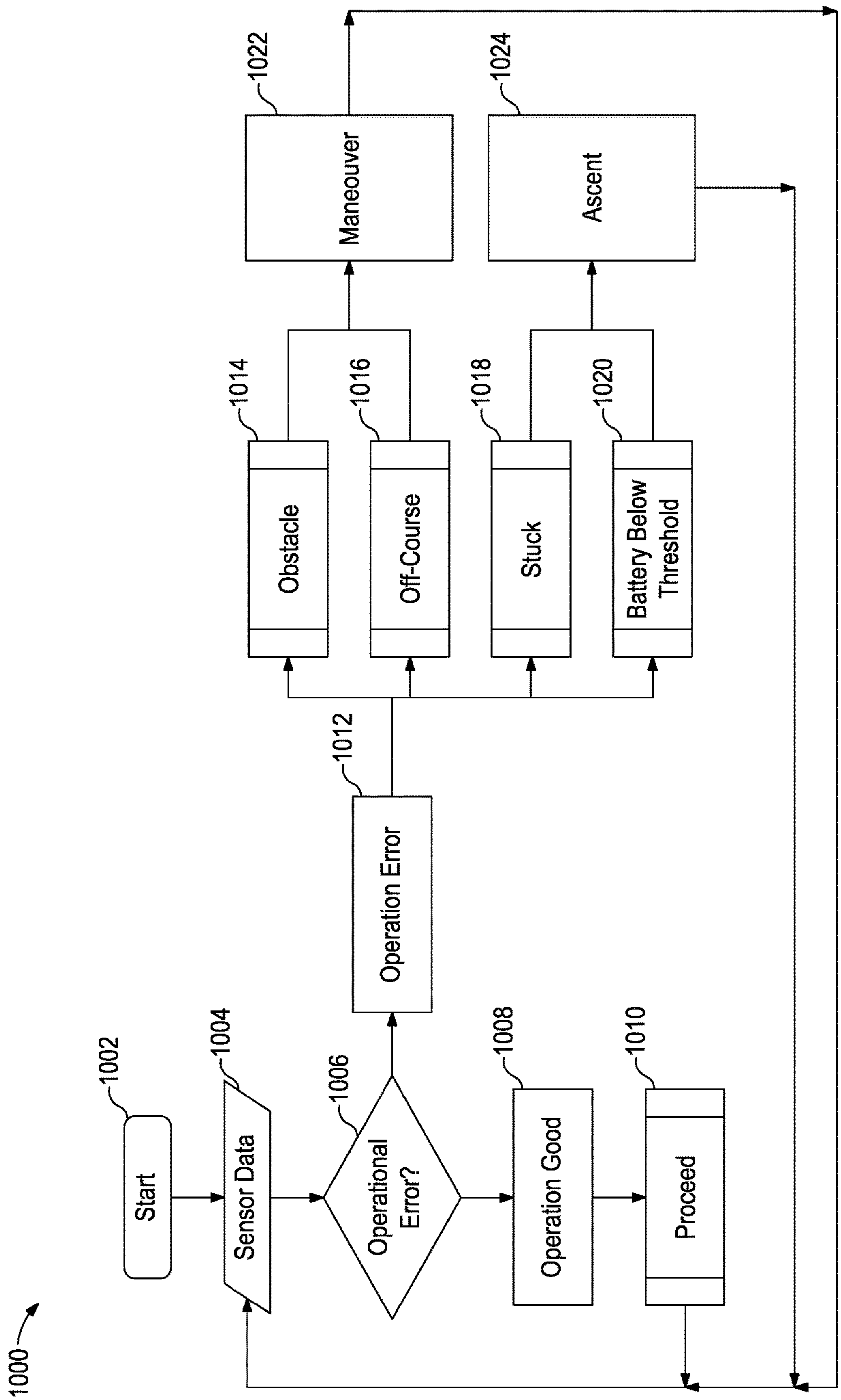

1000
1002
Start
1004
Sensor Data
1006
Operational Error?
1008
Operation Good
1010
Proceed
1012
Operation Error
1014
Obstacle
1016
Off-Course
1018
Stuck
1020
Battery Below Threshold
1022
Maneouver
1024
Ascent

FIG. 10

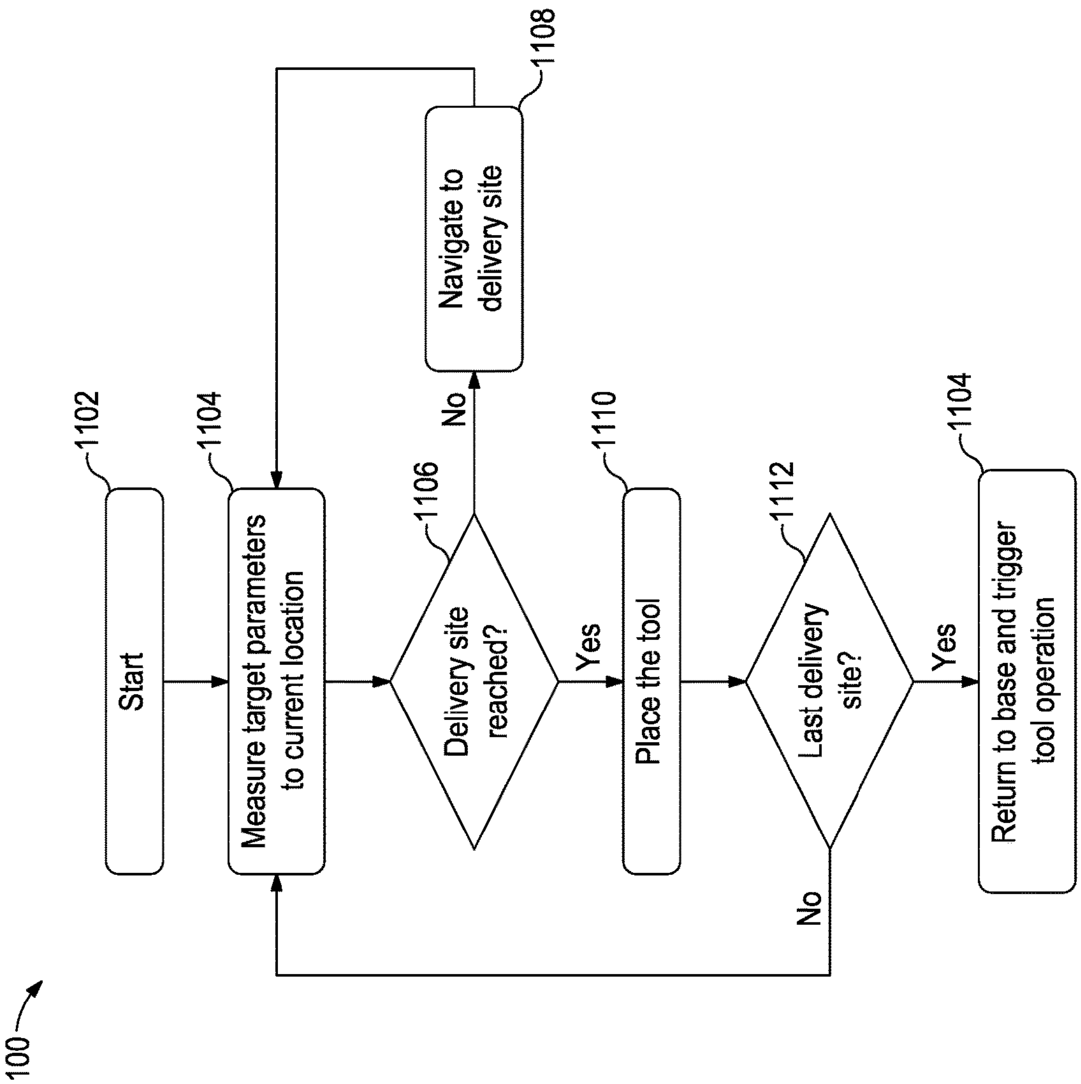

1100
1102
Start
1104
Measure target parameters to current location
1106
Delivery site reached?
No
1108
Navigate to delivery site
Yes
1110
Place the tool
1112
Last delivery site?
No
Yes
1104
Return to base and trigger tool operation

FIG. 11

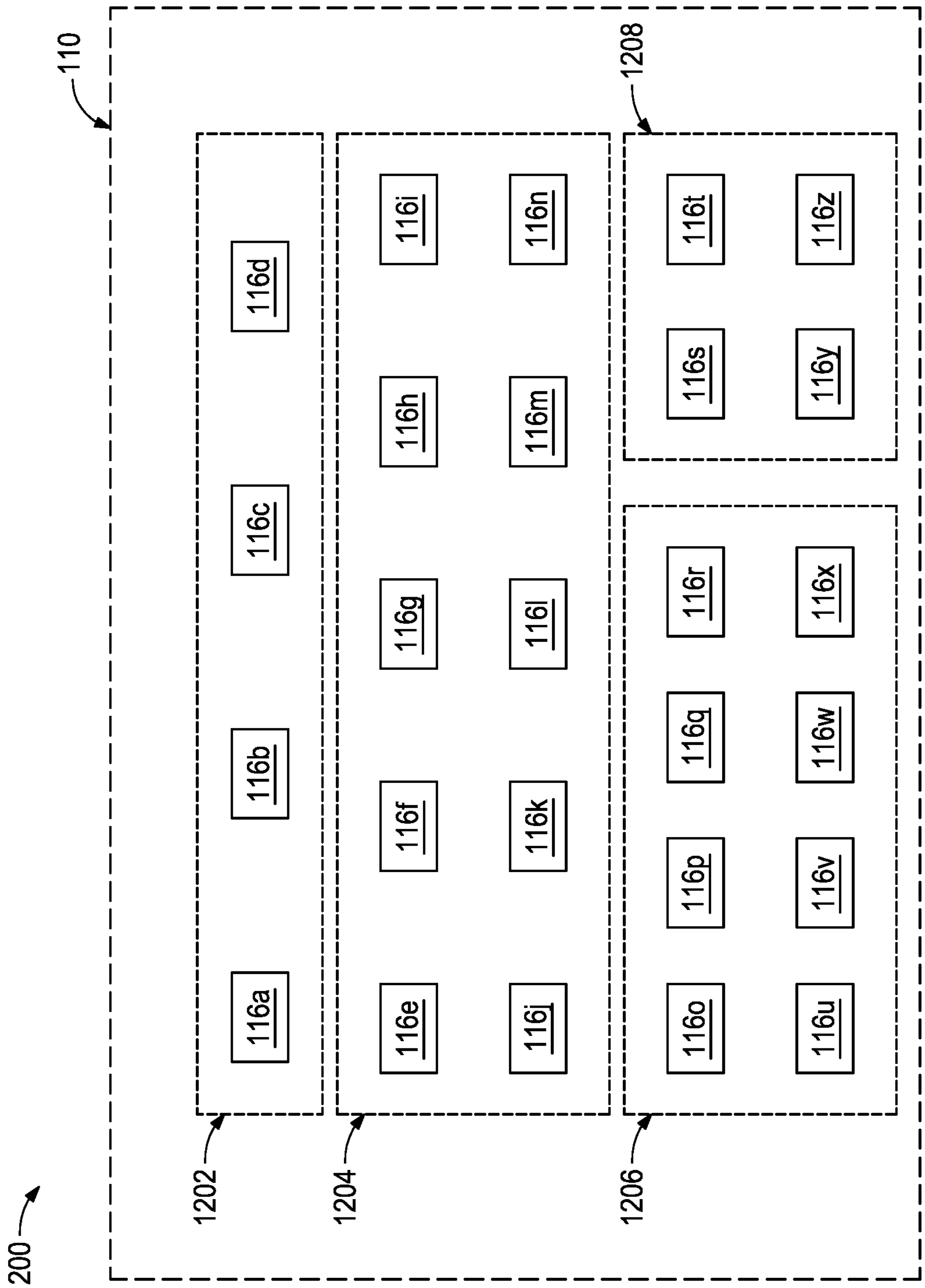

110
1200
1202
1204
1206
1208
116a
116b
116c
116d
116e
116f
116g
116h
116i
116j
116k
116l
116m
116n
116o
116p
116q
116r
116s
116t
116u
116v
116w
116x
116y
116z

FIG. 12

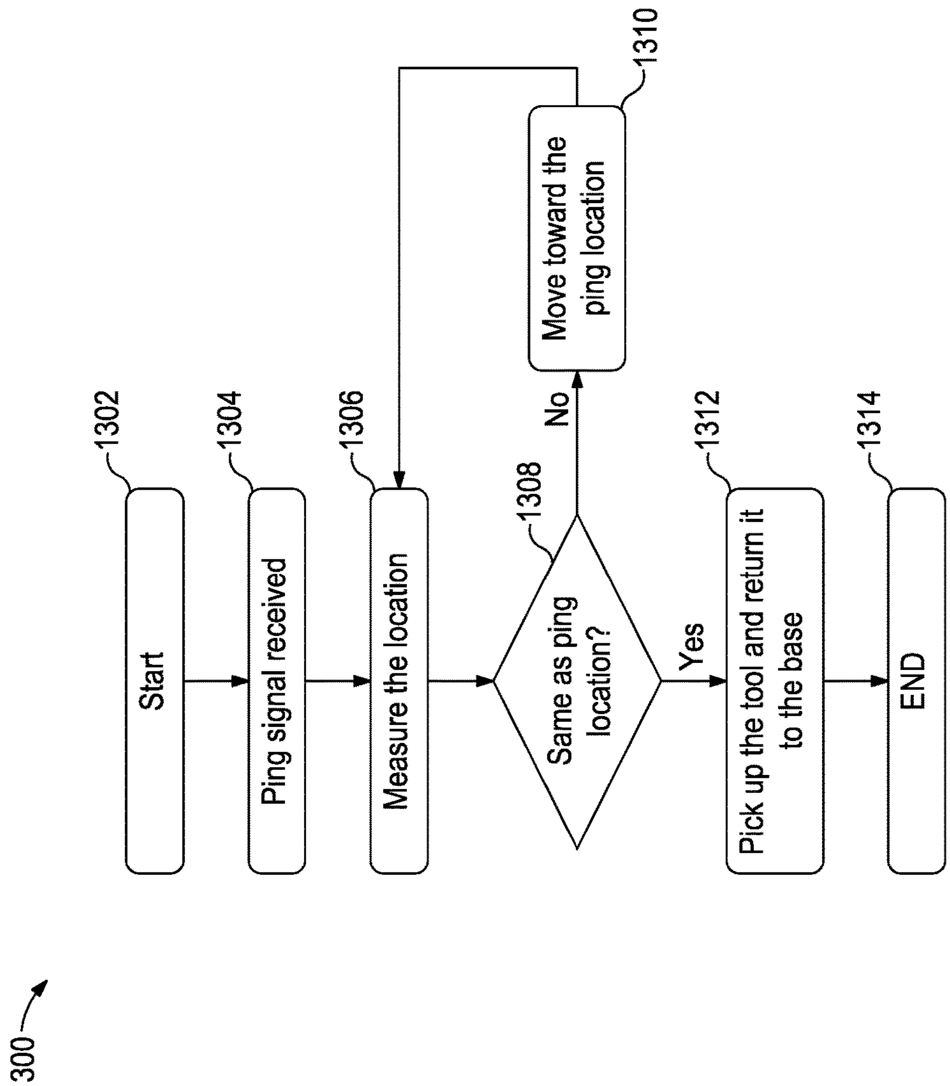

1300
1302
Start
1304
Ping signal received
1306
Measure the location
1308
Same as ping location?
No
1310
Move toward the ping location
Yes
1312
Pick up the tool and return it to the base
1314
END

FIG. 13

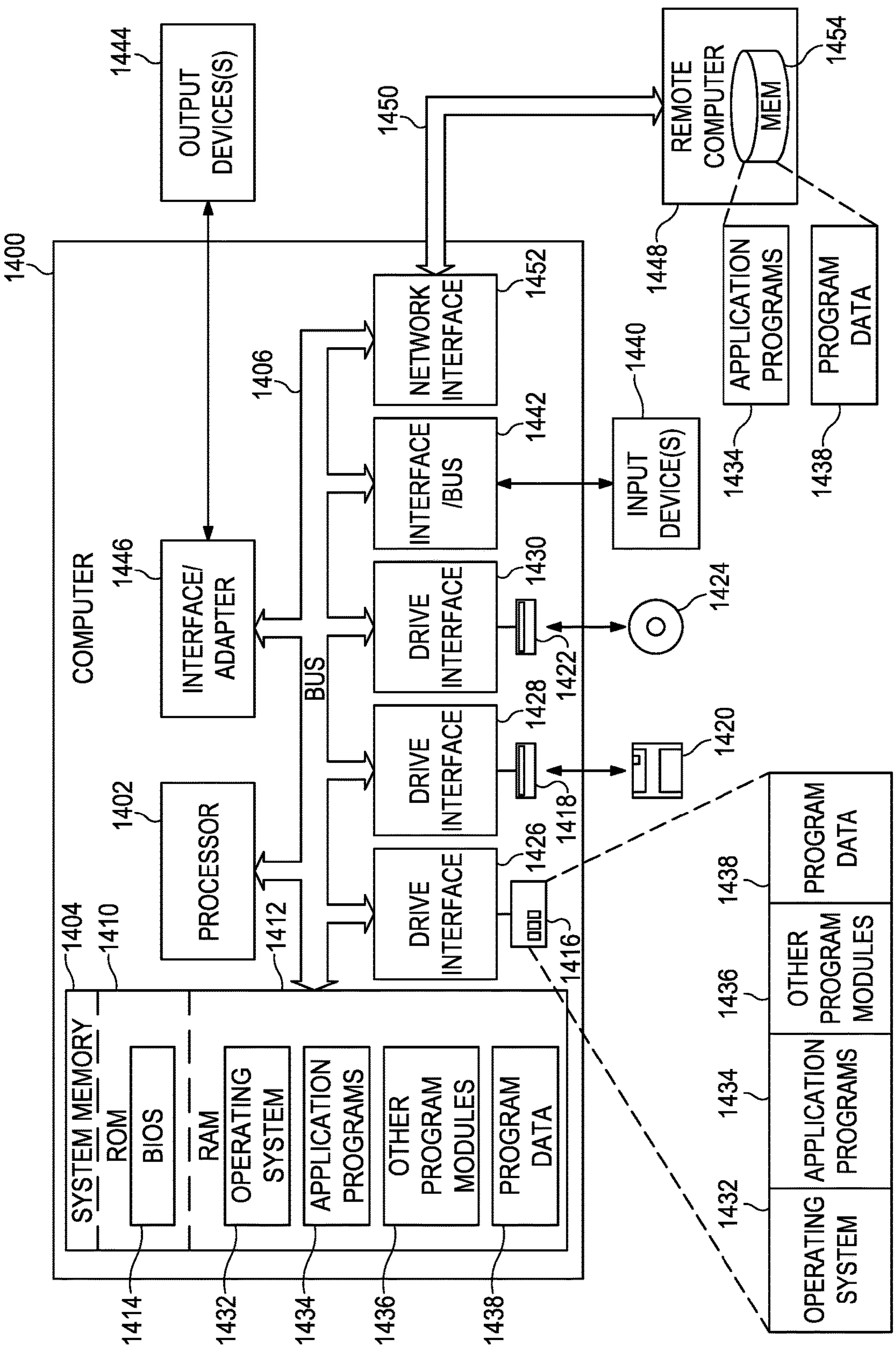

1400
COMPUTER
1444
OUTPUT DEVICES(S)
1446
INTERFACE/ ADAPTER
1402
PROCESSOR
1404
1410
SYSTEM MEMORY
ROM
BIOS
RAM
OPERATING SYSTEM
APPLICATION PROGRAMS
OTHER PROGRAM MODULES
PROGRAM DATA
1414
1432
1434
1436
1438
1412
BUS
1406
DRIVE INTERFACE
1426
DRIVE INTERFACE
1428
DRIVE INTERFACE
1430
INTERFACE /BUS
1442
NETWORK INTERFACE
1452
1416
1418
1422
1420
1424
INPUT DEVICE(S)
1440
1450
REMOTE COMPUTER
MEM
1454
1448
APPLICATION PROGRAMS
PROGRAM DATA
1434
1438
OPERATING SYSTEM
APPLICATION PROGRAMS
OTHER PROGRAM MODULES
PROGRAM DATA
1432
1434
1436
1438

FIG. 14

SYSTEMS AND METHODS FOR ACQUIRING SEISMIC DATA

FIELD OF THE DISCLOSURE

[0001] The present description relates generally to acquiring seismic data.

BACKGROUND OF THE DISCLOSURE

[0002] Directional drilling is a practice of drilling non-vertical wellbores in a subsurface formation. To maximize reservoir contact, drilling plans for directional drilling operations may use formation models. A formation model enables visualization of the subsurface formation, which may include one or more different sedimentary layers including one or more resource deposits. The formation model may be generated using time-domain data, such as seismic data.

[0003] To capture the time-domain data, sources (e.g., seismic vibrators, explosions, acoustic sources) are activated at different locations relative to the subsurface formation. A source at a location generates sonic waves, acoustic waves, or a combination thereof, that propagate toward and through the subsurface formation. The velocity of a wave depends on properties of the subsurface formation (e.g., density, porosity, fluid content). Different sedimentary layers of the subsurface formation have different properties, resulting in different velocities. The waves are reflected back toward the surface when a boundary between two sedimentary layers having different properties is encountered. The reflected waves are received by one or more sensors (e.g., a geophone, a hydrophone, a seismic detector, a sensor for measuring seismic energy or vibrations). The time-domain data is then converted to depth-domain data to generate the formation model, or structural map, of the different sedimentary layers. The formation model may be used to identify impermeable sedimentary layers and faults that may trap hydrocarbons such as oil and gas.

SUMMARY OF THE DISCLOSURE

[0004] Various details of the present disclosure are hereinafter summarized to provide a basic understanding. This summary is not an exhaustive overview of the disclosure and is neither intended to identify certain elements of the disclosure, nor to delineate the scope thereof. Rather, the purpose of this summary is to present some concepts of the disclosure in a simplified form prior to the more detailed description that is presented hereinafter.

[0005] According to an embodiment of the present disclosure, a self-burrowing seismic-sensing tool includes a navigator, implemented by a processor, configured to determine a course to a target destination within a subsurface formation, the course being based on a current location received from one or more sensors, a burrower, implemented by the processor, configured to operate a burrowing device to reach the target destination based on the course, and a data acquisition unit, implemented by the processor, configured to generate seismic data based on seismic waves received at the target destination.

[0006] According to another embodiment of the present disclosure, a computer-implemented method for a self-burrowing seismic-sensing tool is disclosed and includes determining a course to a target destination within a subsurface formation from a surface location, operating a burrowing device to the target destination based on the course, and generating seismic data based on seismic waves received at the target destination.

[0007] According to another embodiment of the present disclosure, a computer-readable medium storing computer-executable instructions is disclosed and, which, when executed by a processor, causes the processor to determine a course to a target destination within a subsurface formation, the course based on a current location received from one or more sensors, operate a burrowing device to the target destination based on the course, and collect seismic data based on seismic waves received at the target destination.

[0008] Any combinations of the various embodiments and implementations described herein can be used in a further embodiment, consistent with the disclosure. These and other aspects and features can be appreciated from the following description of certain embodiments presented herein in accordance with the disclosure and the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a schematic diagram of an example system for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0010] FIG. **2** is a block diagram of an example system for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0011] FIG. **3** is a flow diagram of a method for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0012] FIG. **4** is a block diagram of a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0013] FIG. **5** is a flow diagram of an example method for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0014] FIG. **6** is a schematic diagram of a self-burrowing seismic-sensing tool navigating a subsurface formation, in accordance with certain embodiments.

[0015] FIG. **7** is a flow diagram of an example method for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0016] FIG. **8** is a flow diagram of an example method for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0017] FIG. **9** is a schematic diagram of a self-burrowing seismic-sensing tool navigating a subsurface formation, in accordance with certain embodiments.

[0018] FIG. **10** is a flow diagram of an example method for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0019] FIG. **11** is a flow diagram of an example method for delivering a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0020] FIG. **12** is a block diagram aerial view of a plurality of self-burrowing seismic-sensing tools located within a subterranean formation, in accordance with certain embodiments.

[0021] FIG. **13** is a flow diagram of an example method for retrieving a self-burrowing seismic-sensing tool, in accordance with certain embodiments.

[0022] FIG. **14** is block diagram of a computer system used in accordance with certain embodiments.

DETAILED DESCRIPTION

[0023] Embodiments of the present disclosure will now be described in detail with reference to the accompanying Figures. Like elements in the various figures may be denoted by like reference numerals for consistency. Further, in the following detailed description of embodiments of the present disclosure, numerous specific details are set forth in order to provide a more thorough understanding of the claimed subject matter. However, it will be apparent to one of ordinary skill in the art that the embodiments described herein may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description. Additionally, it will be apparent to one of ordinary skill in the art that the scale of the elements presented in the accompanying Figures may vary without departing from the scope of the present disclosure.

[0024] Embodiments of the present disclosure relate generally to acquiring seismic data. Seismic acquisition using land surveys involves placing one or more sensors on the surface of a subsurface formation to collect seismic data. Seismic data enables imaging, or modeling, of the subsurface formation for purposes such as resource exploration or geological mapping. The one or more sensors may be geophones, hydrophones, seismic detectors, or other like sensors for measuring sonic or acoustic energy or vibrations. Sonic and acoustic energy vibrations are collectively herein referred to as "seismic waves". To generate seismic waves, sources are activated at different surface locations. The sources may be seismic vibrators, explosions, acoustic sources, or other like devices for generating seismic waves. As described above, the seismic waves are reflected back toward the surface when a boundary between two sedimentary layers having different properties is encountered, and the reflected waves are received by the one or more sensors.

[0025] The survey area may cover large areas. The one or more sensors are to be positioned across the survey area at a plurality of locations that ensure an accuracy and resolution of the seismic data collected. The plurality of locations may form a grid pattern across a survey area with a specified spacing between the one or more sensors. The specified spacing may depend upon a targeted level of detail, subsurface conditions, surface conditions, or other like factors. The specified spacing may be tens of meters, for example. The placement of the one or more sensors may involve multiple workers performing an assembly line of activities. For instance, a first worker may mark each location of a plurality of locations, a second worker may dig a hole at each location of the plurality of locations, and yet a third worker may place a sensor in each hole and then fill in the hole.

[0026] However, workers may misplace a sensor introducing a human error that may reduce an accuracy or resolution of the seismic data collected. Additionally, remote locations or harsh environments including one or more of rough terrain, extreme temperatures, dense vegetation, or other like hazardous conditions may be challenging to access, unsafe for workers to survey, or a combination thereof.

[0027] According to embodiments of the present disclosure, a self-burrowing seismic-sensing tool is described and includes a navigator, implemented by a processor, configured to determine a course to a target destination within a subsurface formation, where the course is based on a current location received from one or more sensors. The self-burrowing seismic-sensing tool also includes a burrower, implemented by the processor, configured to operate (direct) a burrowing device to the target destination based on the course and a data acquisition unit, implemented by the processor, configured to generate seismic data based on seismic waves received at the target destination. Self-burrowing, as used herein, indicates that the seismic-sensing tool is semi-autonomous, untethered, and able to burrow itself into the earth's surface. The self-burrowing seismic-sensing tool may also include a command unit, implemented by the processor, configured to receive one or more commands or operational errors and to determine one or more operation modes based upon the one or more commands or operational errors. In response to one or more of the operation modes, the burrower may cause the burrowing device to ascend or descend within the ground, the data acquisition unit may acquire or cease acquiring data, or a transceiver may transmit a signal.

[0028] Using the self-burrowing seismic-sensing tool, as described herein, enables seismic surveys without relying on workers in the land survey area. Removing workers from the process of placing the one or more sensors reduces a likelihood of human error that reduces the accuracy or resolution of the seismic data collected. The workers are also protected from unsafe survey conditions. Additionally, the self-burrowing seismic-sensing tool can be used in other industries outside of oil and gas, for example, in the mining industry, the quarry industry, the hydrological industry, the liquid waste disposal industry, the geothermal energy industry, the agriculture industry, the geologic greenhouse gas storage industry, or like industries in which drilling or quarrying of subterranean formations can be performed or submersing underground sensors is required.

[0029] FIG. **1** is a schematic diagram of an example system **100** for acquiring seismic data using a self-burrowing seismic-sensing tool, shown as tools **116***a*, **116***b*, **116***c*, **116***z*, in accordance with certain embodiments. Self-burrowing seismic-sensing tools **116***a*, **116***b*, **116***c*, **116***z* may herein be referred to collectively as the self-burrowing seismic-sensing tools **116**. The self-burrowing seismic-sensing tools **116** receive seismic waves **117** and generate seismic data in response to receipt of the seismic waves **117**.

[0030] In certain embodiments, the self-burrowing seismic-sensing tools **116** may be delivered and/or retrieved by one or more aerial delivery tools **118** or land delivery tools **120** to and/or from a survey area **102**. Aerial delivery tool **118** may be a drone, a remotely operated airplane, an autonomous aerial vehicle, or other like unmanned aerial vehicle. Land delivery tool **120** may be a remotely operated land vehicle, an autonomous ground vehicle, or other like unmanned ground vehicles. The unmanned ground vehicle may be wheeled or legged, for example. One or more of the aerial delivery tool **118** or the land delivery tool **120** may include one or more robotic arms, clamps, or other like systems for delivering or retrieving the self-burrowing seismic-sensing tools **116**. The survey area **102** may be a remote location or harsh environment. In a non-limiting example, the survey area **102** may be a field having a subsurface formation **110** present below the surface of the earth and being explored or developed for hydrocarbons. The field may include a rig **124** communicatively coupled to a control site **122**, for example.

[0031] Each self-burrowing seismic-sensing tool **116** is delivered to a surface location of the subsurface formation **110**. In a non-limiting example, the self-burrowing seismic-sensing tools **116** are delivered to different surface locations based on a global positioning system (GPS), geographic coordinate system, or other like mapping system. In another non-limiting example, the self-burrowing seismic-sensing tools **116** are delivered at different distances relevant to a specified reference site. The specified reference site may be determined by an operator of the system **100**, a seismic survey plan, or the like. The specified reference site may be associated with a grid system, for example. Grid system, as used herein, is a mapping system providing reference coordinates for multiple self-burrowing seismic-sensing tools, for example. The grid system may be a two-dimensional or three-dimensional system. For example, in addition to coordinates along an x-axis and a y-axis, z-axis coordinates could be used to specify an elevation or a depth. The specified reference site may be the rig **124** or the control site **122**, for example. In a non-limiting example, self-burrowing seismic-sensing tool **116***a* may be located at a first distance from the rig **124**, self-burrowing seismic-sensing tool **116***b* may be located at a second distance that is further from the rig **124** than the self-burrowing seismic-sensing tool **116***a*, self-burrowing seismic-sensing tool **116***c* may be located at a third distance that is further from the rig **124** than the self-burrowing seismic-sensing tools **116***a* and **116***b*, and self-burrowing seismic-sensing tool **116***z* may be located at a fourth (or zth) distance that is further from the rig **124** than the self-burrowing seismic-sensing tools **116***a*, **116***b*, and **116***c*.

[0032] In certain embodiments, the self-burrowing seismic-sensing tools **116** may each be delivered along a substantially linear path. Substantially, as used herein, indicates that each of the self-burrowing seismic-sensing tools **116** are within a specified threshold distance of the linear path. The specified threshold distance may be determined by an operator of the system **100**, may be included in a seismic survey plan associated with subsurface formation **110**, or the like. The specified threshold distance may be dependent upon geologic surface features that impede placement of one or more of the self-burrowing seismic-sensing tools **116** in a position that is disposed along the linear path, for example.

[0033] In various embodiments, to generate seismic waves **117**, one or more sources (e.g., seismic vibrators, explosions, acoustic sources) (not explicitly shown) are activated at different control points (e.g., one or more surface locations specified in a seismic survey plan, by an operator of the system **100**, or the like) along a surface of the subsurface formation **110**. The sources may be activated at different surface locations of the subsurface formation **110**. The sources generate seismic waves **117** that propagate in the subsurface formation **110**, and are reflected back toward the surface when a boundary between two sedimentary layers **112** having different properties is encountered. The reflected seismic waves **117** are received by the self-burrowing seismic-sensing tools **116**. The self-burrowing seismic-sensing tools **116** may generate seismic data based on the seismic waves **117**.

[0034] The seismic data may be stored to a computer-readable medium. The computer-readable medium may be a computer-readable medium as described with respect to FIG. **14**, for example. The computer-readable medium may be local to the self-burrowing seismic-sensing tools **116** or remote to the self-burrowing seismic-sensing tools **116**. For example, the computer-readable medium may be a computer-readable medium of the self-burrowing seismic-sensing tools **116**, a cloud provider **104**, or a computing device **134** at a facility **132** of a remote location **106**. In a non-limiting example, the self-burrowing seismic-sensing tools **116**, the cloud provider **104**, or the remote computing device **134** are communicatively coupled via a wired connection (e.g., cable) or a wireless connection (e.g., Wi-Fi, Bluetooth). One or more communication relays **108** (e.g., satellite, antenna, modem, router, network hub, or the like) may facilitate the communication connections.

[0035] In various embodiments, the cloud provider **104** provides resources, such as infrastructure-as-a-service (IaaS) (e.g., computing resources such as processing and storage, security), software-as-a-service (SaaS) (e.g., web-based tools), or the like via the internet. In a non-limiting example, the cloud provider **104** may host a seismic modeling tool **130**. The seismic modeling tool **130** may be communicatively coupled to the computer-readable medium storing seismic data generated by the self-burrowing seismic-sensing tools **116**. The seismic modeling tool **130** may use the seismic data to generate or update a formation model of the subsurface formation **110**, for example. The formation model may include the different sedimentary layers **112** as well as a geological feature **114**, for example. In a non-limiting example, the formation model may be used to steer a drill bit **128** operatively coupled to a bottom-hole assembly (BHA) **126**.

[0036] While the seismic modeling tool **130** is shown as hosted by the cloud provider **104**, in other examples, the seismic modeling tool **130** may be located on the remote computing device **134**. Deploying the self-burrowing seismic-sensing tools **116** in the field being explored or developed for hydrocarbons using the rig **124** enables high fidelity modeling of the subsurface formation **110**. High fidelity modeling of the subsurface formation **110** may mitigate the risk of collapse of the rig **124** created by drilling into unstable formations.

[0037] In some embodiments, each self-burrowing seismic-sensing tool **116** may be equipped with a wireless communication unit capable of underground communication (e.g., Wi-Fi, Bluetooth, etc.) with other wireless communication units. In at least one embodiment, the communication relay **108** may help facilitate the wireless communication between each self-burrowing seismic-sensing tool **116**. In such embodiments, the self-burrowing seismic-sensing tools **116** may create a network of underground sensors, where each sensor collects a seismic wave and subsequently transmits the seismic data to a nearby self-burrowing seismic-sensing tools **116** to transmit or "hop" the data. The data continues to be transmitted or "hopped" to nearby self-burrowing seismic-sensing tools **116** until it reaches the self-burrowing seismic-sensing tool **116** closest to the control site **122** at the surface. As will be appreciated, this may help achieve real-time seismic data acquisition. Moreover, this embodiment may be applicable to establishing an underground network of sensors and a corresponding underground internet of things (UIoT).

[0038] FIG. **2** is a block diagram of an example system **200** for acquiring seismic data using a self-burrowing seismic-sensing tool **220**, in accordance with certain embodiments. The system **200** may be the system **100**, for example. The delivery tool **202** may deliver the self-burrowing seismic-sensing tool **220** to a survey area. The delivery tool **202** may be the aerial delivery tool **118** or the land delivery tool **120** described with respect to FIG. **1**, for example. The self-burrowing seismic-sensing tool **220** may generate seismic data based on seismic waves received during seismic surveying of a subsurface formation. The self-burrowing seismic-sensing tool **220** may be the self-burrowing seismic-sensing tool **116***a*, **116***b*, **116***c*, **116***z* described with respect to FIG. **1**, for example. The seismic modeling tool **130** may receive the seismic data to generate a formation model for the subsurface formation.

[0039] In certain embodiments, the delivery tool **202** includes a processor **204** coupled to a sensor **206**, a transceiver **208**, a power supply **210**, a delivery apparatus **212**, and a computer-readable medium **214** storing machine-readable instructions **216**. The processor **204** may be a processor described with respect to FIG. **14**, for example. The sensor **206** may include one or more of an electromagnetic sensor, a global positioning sensor (GPS), a radar sensor, a LIDAR sensor, an image sensor, a gravity sensor (e.g., an accelerometer), a proximity sensor, an altitude sensor, a pressure sensor, or other like sensors for determining a location of and detecting hazards to the delivery tool **202**. The power supply **210** may be one or more of a generator, a battery, photovoltaic cells, or other like sources of energy for powering the delivery tool **202**. The delivery apparatus **212** may be one or more robotic arms, one or more clamps, or other like electromechanical devices for carrying, releasing, and/or retrieving objects. The computer-readable medium **214** may be a computer-readable medium as described with respect to FIG. **14**, for example. In a non-limiting example, the machine-readable instructions **216**, when executed by the processor **204**, cause the processor to operate the delivery tool **202** as described with respect to FIG. **3**.

[0040] In certain embodiments, the self-burrowing seismic-sensing tool **220** includes a processor **222** coupled to a first sensor **224**, a second sensor **226**, a transceiver **228**, a power supply **230**, a burrowing apparatus **232**, and a computer-readable medium **234** storing machine-readable instructions **236**. The processor **222** may be a processor described with respect to FIG. **14**, for example. The first sensor **224** may be an electromagnetic sensor, a global positioning sensor (GPS), a radar sensor, a LIDAR sensor, a gravity sensor (e.g., an accelerometer), a proximity sensor, an image sensor, an altitude sensor, a pressure sensor, or other like sensor for determining a location of and detecting hazards to the self-burrowing seismic-sensing tool **220**. The second sensor **226** may be a geophone, a hydrophone, a seismic detector, or other like sensors for measuring seismic energy or vibrations. The power supply **230** may be one or more of a generator, a battery, photovoltaic cells, or other like sources of energy for powering the self-burrowing seismic-sensing tool **220**. The burrowing apparatus **232** may be one or more robotic arms, one or more drills, or other like electromechanical devices configured to and otherwise capable of advancing into the subsurface formation **110** (FIG. **1**) or "burrowing" into the subsurface formation **110**. The computer-readable medium **234** may be a computer-readable medium as described with respect to FIG. **14**, for example. In a non-limiting example, the machine-readable instructions **216**, when executed by the processor **204**, cause the processor to operate the delivery tool **202** as described with respect to FIG. **3**. In a non-limiting example, the self-burrowing seismic-sensing tool **220** may also include one or more components of the delivery tool **202** to enable the self-burrowing seismic-sensing tool **220** to deliver and/or retrieve itself or other self-burrowing seismic-sensing tools to a survey area.

[0041] FIG. **3** is a flow diagram of an example method **300** for acquiring seismic data using a self-burrowing seismic-sensing tool, in accordance with certain embodiments. The self-burrowing seismic-sensing tool may be the self-burrowing seismic-sensing tool **116***a*, **116***b*, **116***c*, **116***z* described herein with respect to FIG. **1**, or the self-burrowing seismic-sensing tool **220** described herein with respect to FIG. **2**, for example. In certain embodiments, method **300** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **300** includes starting (block **302**), receiving target parameters (block **304**), navigating to a delivery site (block **306**), descending to a target destination (block **308**), collecting seismic data (block **310**), ascending to the surface (block **312**), and navigating to a base (block **314**).

[0042] Starting block **302** includes, but is not limited to, receiving an input from a user, the present system, another system, or a combination thereof, which indicates the present system is to perform the method **300**. The user may use a computer system, such as the remote computing device **134** of FIG. **1**, to input data or a command, for example. In a non-limiting example, the input may be a command to execute a computer application (e.g., the seismic modeling tool **130** of FIG. **1**). A computer application, as used herein, may include any type of application, program, or automated process having computer-executable instructions, which, when executed by a processor (not explicitly shown), enable access to specified operations or data. The user may use a graphical user interface (GUI) of the computer application to indicate the present system is to perform the method **300**, for example. The computer application may include an application programming interface (API) server, a web server, or other like interface component (not explicitly shown) that enables communication between the computer application and the self-burrowing seismic-sensing tool for example. In another non-limiting example, the input may be a command from another tool. The other tool may be another self-burrowing seismic-sensing tool or a delivery tool, for example. The delivery tool may be the aerial delivery tool **118** of FIG. **1**, the land delivery tool **120** of FIG. **1**, or the delivery tool **202** of FIG. **2**, for example.

[0043] Receiving the target parameters at block **304** includes, but is not limited to, receiving the target parameters from one or more computer-readable medium, input devices, network interfaces (e.g., receiving the target parameters via a transceiver or communication relay), or a combination thereof, associated with the present system, another system, or a combination thereof. The target parameters may include one or more delivery sites, one or more target destinations, one or more target depths, a specified reference site, one or more elevations, one or more distances, or a combination thereof. Alternatively, or in addition thereto, the target parameters may be based on magnetic sensors (e.g., Hall effect sensors) included in the robot and operable to sense a magnetic field generated at the surface, which allows the robot to navigate itself to the source for accurate retrieval. Delivery site, as used herein, is a surface location to which a self-burrowing seismic-sensing tool is to be delivered. Target destination, as used herein, is a subsurface location to which the self-burrowing seismic-sensing tool is to burrow (advance underground) to acquire seismic data. The target destination may be based on GPS coordinates, a geographic coordinate system, or other like mapping system. The target depth, as used herein, is a depth to which the self-burrowing seismic-sensing tool is to burrow to acquire seismic data. The target depth may be relative to an elevation of a delivery site, for example. In another non-limiting example, the target depth may be a depth of the subsurface formation through which the self-burrowing seismic-sensing tool is to burrow. For example, target parameters for a delivery tool (e.g., the aerial delivery tool **118** of FIG. **1**, the land delivery tool **120** of FIG. **1**, the delivery tool **202** of FIG. **2**) may include one or more of a specified reference site, multiple distances, or multiple delivery sites to which to deliver multiple self-burrowing seismic-sensing tools (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**). In another example, target parameters for the self-burrowing seismic-sensing tool may also include a specified depth to which the self-burrowing seismic-sensing tool is to burrow from one or more of a delivery site or a reference elevation.

[0044] Navigating to delivery site at block **306** may include performing one or more steps of the method **1100**, as described below with reference to FIG. **11**. Descending to the target at block **308** may include performing one or more steps of the method **500** described below with reference to FIG. **5**. Collecting seismic data at block **310** may include performing one or more steps of the method **700** described below with reference to FIG. **7**. Ascending to the surface at block **312** may include performing one or more steps of the method **800** described below with reference to FIG. **8**. Navigating to base at block **314** may include performing one or more steps of the method **1100** described herein with reference to FIG. **11**.

[0045] FIG. **4** is a block diagram of a self-burrowing seismic-sensing tool **404**, in accordance with certain embodiments. The self-burrowing seismic-sensing tool **404** may be the self-burrowing seismic-sensing tool **116***a*, **116***b*, **116***c*, **116***z* described with respect to FIG. **1** or the self-burrowing seismic-sensing tool **220** described with respect to FIG. **2**, for example. The self-burrowing seismic-sensing tool **404** is configured to receive one or more of commands **402**, target parameters **403**, seismic waves (e.g., seismic waves **117** of FIG. **1**), or a combination thereof, and to generate seismic data **416** based on the seismic waves.

[0046] In certain embodiments, self-burrowing seismic-sensing tool **404** includes a navigator **408**, implemented by a processor (e.g., the processor **222** of FIG. **2**), and configured to determine a course to a target destination within a subsurface formation (e.g., subsurface formation **110** of FIG. **1**) based on a current location received from one or more sensors (e.g., first sensor **224** of FIG. **2**, second sensor **226** of FIG. **2**), a burrower **410**, implemented by the processor, and configured to operate a burrowing device (e.g., burrowing apparatus **232** of FIG. **2**) to the target destination based on the course, and a data acquisition unit **412**, implemented by the processor, and configured to generate seismic data **416** based on seismic waves received at the target destination. The current location may include one or more coordinates based on a mapping system, an elevation, a depth, or a combination thereof. Self-burrowing seismic-sensing tool **404** may also include a command monitor **406**, implemented by the processor, configured to receive one or more commands **402** or operational errors and to determine one or more operation modes based upon the one or more commands **402** or operational errors. Command monitor **406** may determine the one or more operation modes by performing one or more steps of the method **1000** described with reference to FIG. **10**, for example.

[0047] In a non-limiting example, the one or more operation modes may indicate one or more of descent, ascent, course planning, data acquisition, delivery, retrieval, hopping a communication signal, or an operational error, for example. Operational errors may include navigational errors (e.g., obstacle encountered, proximity to obstacle, off course, or the like) and system errors. Self-burrowing seismic-sensing tool may also include system monitor **414**, implemented by the processor, and configured to monitor for one or more system errors. The one or more system errors may indicate that one or more components of the self-burrowing seismic-sensing tool **404** are functioning outside normal parameters. The one or more system errors may indicate that a battery charge is below a specified threshold, that a sensor output indicates a sensor is non-operable, or that a burrowing apparatus is non-operable, for example.

[0048] In various embodiments, the navigator **408** determines the course by performing one or more steps of the method **500** described with respect to FIG. **5** or the method **800** described with respect to FIG. **8**. In some embodiments, the burrower **410** causes the burrowing device to descend in response to the one or more operation modes indicating to descend, or to ascend in response to the one or more operation modes indicating to ascend. The burrower **410** may cause the burrowing device to descend to the target by performing one or more steps of the method **500** described with respect to FIG. **5**, for example. The burrower **410** may cause the burrowing device to ascend to the surface by performing one or more steps of the method **800** described with respect to FIG. **8**, for example. In other embodiments, the data acquisition unit **412** acquires data in response to the one or more operation modes indicating to begin seismic data acquisition and ceases acquiring data in response to the one or more operation modes indicating to cease seismic data acquisition. The data acquisition unit **412** may generate seismic data **416** by performing one or more steps of the method **700** described with respect to FIG. **7**, for example. In various embodiments, the command monitor **406** causes a transceiver (e.g., transceiver **228** of FIG. **2**) to transmit a signal in response to the one or more operation modes indicating that the self-burrowing seismic-sensing tool **404** is waiting for retrieval.

[0049] In certain embodiments, the navigator **408** may receive target parameters **403**. The navigator **408** may receive target parameters **403** from one or more of computer-readable medium, input devices, network interfaces (e.g., receiving the target parameters via a transceiver or communication relay from a computer application of a remote system (e.g., seismic modeling tool **130** of FIG. **1**, remote computing device **134** of FIG. **1**)), for example. In a non-limiting example, the navigator **408** may navigate to a delivery site associated with the target destination. The navigator **408** may perform one or more steps of the method **1100** described with respect to FIG. **11** to navigate to the delivery site, for example. In other embodiments, command monitor **406** may receive target parameters **403** in conjunction with, or subsequent to, command **402**. Command **402** may be a signal received via a transceiver (e.g., transceiver **228** of FIG. **2**). The signal may include a command indicating that the self-burrowing seismic-sensing tool **404** is to receive target parameters **403**, for example. In other examples, the command **402** may be a signal that indicates to plan a course, descend, travel to a delivery site, travel to a base, act as a communication relay, or output seismic data **416**. In a non-limiting example, in response to receiving command **402** to output seismic data **416**, command monitor **406** may cause data acquisition unit **412** to output seismic data **416**.

[0050] In various embodiments, the command monitor **406** may receive additional commands from one or more of navigator **408**, burrower **410**, or system monitor **414**. For example, navigator **408** may generate a command indicating that a course has been planned. The course may be a course for descending or ascending (e.g., through the ground below the earth's surface), and in a non-limiting example, navigator **408** may generate a different command based on the type of course planned. In another non-limiting example, navigator **408** may generate a command based on sensor input (e.g., the first sensor **224** of FIG. **2**). Navigator **408** may determine the self-burrowing seismic-sensing tool **404** is off course based on the sensor input, and may generate a command (or signal) indicating that the self-burrowing seismic-sensing tool **404** is off course, for example. In other non-limiting examples, the burrower **410** may generate a command based on sensor input that that the target destination has been reached, an obstacle has been encountered, or a surface location has been reached, and the burrower **410** may generate a command indicating the event associated with the sensor input. In a non-limiting example, system monitor **414** may generate different commands in response to different operational errors.

[0051] FIG. **5** is a flow diagram of an example method **500** for acquiring seismic data (e.g., seismic data **416** of FIG. **4**) using a self-burrowing seismic-sensing tool (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**, self-burrowing seismic-sensing tool **404** of FIG. **4**) in accordance with certain embodiments. One or more components of the self-burrowing seismic-sensing tool may perform one or more steps of method **500**, for example. In certain embodiments, method **500** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **500** includes starting (block **502**), measuring for a reference to a target destination (block **504**), planning a course (block **506**), descending on course (block **508**), comparing a current location to the course (block **510**), determining whether the self-burrowing seismic-sensing tool is on course (block **512**), updating course to the target destination (block **514**), maneuvering (block **516**), determining whether the target destination has been reached (block **518**), ceasing descent (block **520**) and triggering data collection (block **522**).

[0052] Starting block **502** includes, but is not limited to, receiving an input from a user, the present system, another system, or a combination thereof, which indicates the present system is to perform the method **500**. In a non-limiting example, the input may be target parameters (e.g., target parameters **403** of FIG. **4**). In another non-limiting example, the input may be a command from another tool. The other tool may be another self-burrowing seismic-sensing tool or a delivery tool, for example, such as the aerial delivery tool **118** of FIG. **1**, the land delivery tool **120** of FIG. **1**, or the delivery tool **202** of FIG. **2**. The command may include one or more of a command to start operations or to receive the target parameters.

[0053] Measuring for a reference to a target destination at block **504** may include determining one or measurements. The method **500** may include determining a measurement between a current location of the self-burrowing seismic-sensing tool and the target destination. The current location may be a surface location associated with a delivery site of the self-burrowing seismic-sensing tool, for example. Method **500** may include determining the current location using a sensor. The current location may be determined by navigator **408** of FIG. **4** using an input from the first sensor **224** of FIG. **2**, for example. In some embodiments, method **500** includes determining one or more of a distance from the current location to the target destination or a difference in elevation between the current location and the target destination. The method **500** may include storing to a computer-readable medium the current location, the distance, or the difference in elevation as the reference.

[0054] Planning the course at block **506** may include determining one or more steps for the self-burrowing seismic-sensing tool to perform to navigate from the current location to the target destination. In a non-limiting example, the course is a direct, or path of least distance, to burrow from the current location to the target destination. In certain embodiments, method **500** may include using one or more sensors to determine a layout of a surrounding surface area. Method **500** may include determining a surface route around an obstacle to navigate the self-burrowing seismic tool to a second surface location that is different than the delivery site. The second surface location may decrease a burrowing distance from the surface to the target destination, for example. Method **500** may also include determining a route around partially buried or fully buried obstacles. Locations of the buried obstacles may be stored to a computer-readable medium of the self-burrowing seismic-sensing tool, for example. The route around the partially buried or fully buried obstacles may include one or more of a surface route or a burrowing route. In a non-limiting example, the course may include one or more of directions, distances, coordinates, elevations, depths, or like parameters to aid in navigation. In some examples, the criteria (e.g., obstacle, action to take) for determining the course may be determined by an operator of the system, a seismic survey plan, or the like. The criteria (e.g., obstacle, action to take) for planning the course may be stored to a computer-readable medium of the self-burrowing tool or the delivery tool, for example.

[0055] Descending on the course at block **508** may include actuating a burrowing device. In a non-limiting example, the burrower **410** of FIG. **4** may actuate the burrowing apparatus **232** of FIG. **2**. The burrowing device may burrow through the subsurface formation based upon the course determined at block **506**, for example.

[0056] In various embodiments, method **500** includes determining a current location of the self-burrowing seismic-sensing tool at periodic intervals. The periodic interval may be specified by an operator of the system, a seismic survey plan, or the like. The periodic interval may be stored to a computer-readable medium of the self-burrowing tool or the delivery tool, for example. Method **500** includes comparing the current location to the course at block **510**. In a non-limiting example, method **500** includes generating an indicator in response to the comparison. For example, method **500** may include generating a first indicator in response to the comparison indicating that the current location deviates from the course by a specified threshold and a second indicator in response to the comparison indicating the current location does not deviate from the course by more than the specified threshold. The specified threshold may be specified by an operator of the system, a seismic survey plan, or the like. The specified threshold may be stored to a computer-readable medium of the self-burrowing tool or the delivery tool, for example.

[0057] In some embodiments, method **500** includes determining whether the self-burrowing seismic-sensing tool is on course at block **512** based on a result of the comparison. For example, in response to the first indicator, method **500** may include determining that the self-burrowing seismic-sensing tool is off course and in response to the second indicator, method **500** may include determining that the self-burrowing seismic-sensing tool is on course. In various embodiments, in response to a determination that the self-burrowing seismic-sensing tool is off course, method **500** includes updating the course to the target destination, as at bock **514**. In a non-limiting example, method **500** may include determining one or measurements between a current location of the self-burrowing seismic-sensing tool and the target destination. Method **500** may also include determining one or more steps for the self-burrowing seismic-sensing tool to perform to navigate from the current location to the target destination. Method **500** may include performing one or more maneuvers at block **516** to re-position the self-burrowing seismic-sensing tool for descent according to the updated course at block **508**. In a non-limiting example, the one or more maneuvers may be stored to a computer-readable medium of the self-burrowing seismic-sensing tool. The one or more maneuvers may include actuating different components of the self-burrowing seismic-sensing tool, such as a drill bit, a vibration generator, one or more actuators, or any combination thereof.

[0058] In other embodiments, in response to a determination that the self-burrowing seismic-sensing tool is on course, method **500** includes determining whether the target destination has been reached at block **518**. Method **500** includes comparing the current location to the target destination to determine whether the target destination has been reached, for example. In a non-limiting example, method **500** includes generating an indicator in response to the comparison. For example, method **500** may include generating a first indicator in response to the comparison indicating that the current location deviates from the target destination by less than a specified threshold and a second indicator in response to the comparison indicating the current location does not deviate from the target destination by less than the specified threshold. The specified threshold may be specified by an operator of the system, a seismic survey plan, or the like. The specified threshold may be stored to a computer-readable medium of the self-burrowing tool or the delivery tool, for example.

[0059] In some embodiments, method **500** includes determining whether the self-burrowing seismic-sensing tool has reached the target destination at block **518** based on a result of the comparison. For example, in response to the first indicator, method **500** may include determining that the self-burrowing seismic-sensing tool is at the target destination, and in response to the second indicator, method **500** may include determining that the self-burrowing seismic-sensing tool has not reached the target destination. In various embodiments, in response to a determination that the self-burrowing seismic-sensing tool is not at the target destination, method **500** includes continuing descent according to the current course at block **508**. In response to a determination that the self-burrowing seismic-sensing tool is at the target destination, method **500** may include ceasing descent of the burrowing device.

[0060] In various embodiments, triggering data collection at block **522** may include generating one or more commands. Method **500** may include updating an operation mode to trigger a data acquisition unit, for example. The data acquisition unit may be the data acquisition unit **412** of FIG. **4**, for example. In a non-limiting example, triggering the data acquisition unit may supply power to the data acquisition unit. In another non-limiting example, method **500** may include sending a command to the data acquisition unit to begin recording seismic data in response to receipt of seismic waves. Method **500** may also include storing the seismic data to a computer-readable medium of the self-burrowing seismic-sensing tool.

[0061] FIG. **6** is a schematic diagram of an example self-burrowing seismic-sensing tool **116***a* navigating the subsurface formation **110**, in accordance with certain embodiments. Upon arrival at a delivery site, self-burrowing seismic-sensing tool **116***a* may receive a signal. The signal may include one or more of a command to start burrowing operations or target parameters. Self-burrowing seismic-sensing tool **116***a* may perform one or more measurements in response to receiving the signal. Self-burrowing seismic-sensing tool **116***a* may determine a current location “A”, for example. Self-burrowing seismic-sensing tool **116***a* may also determine a distance (“d”) from the current location to the target destination (“target”). The distance may be a depth to which the self-burrowing seismic-sensing tool is to burrow (i.e., advance into the subsurface formation **110**) or a difference in elevation between the current location and the target destination, for example. Self-burrowing seismic-sensing tool **116***a* may plan course **602***a* to navigate from “A” to the “target” using the measurements. Self-burrowing seismic-sensing tool **116***a* may plan course **602***a* to route around obstacle **604**, for example.

[0062] In certain embodiments, after determining course **602***a*, self-burrowing seismic-sensing tool **116***a* may actuate a burrowing apparatus included on or forming part of the self-burrowing seismic-sensing tool **116***a*. Self-burrowing seismic-sensing tool **116***a* may burrow through the subsurface formation **110** based upon course **602***a*. Self-burrowing seismic-sensing tool **116***a* may receive one or more sensor inputs while traversing course **602***a*. In a non-limiting example, in response to a determination that a distance “c” between obstacle **604** and current location “B” of the self-burrowing seismic-sensing tool **116***a* is outside a specified threshold, self-burrowing seismic-sensing tool **116***a* may determine second course **602***b* from current location “B” to “target.” The specified threshold may be specified by an operator of the system, a seismic survey plan, or the like. The specified threshold may be stored to a computer-readable medium of the self-burrowing tool **116***a*, for example. Self-burrowing seismic-sensing tool **116***a* may continue to burrow through the subsurface formation **110** based upon course **602***b*. Upon reaching “target,” self-burrowing seismic-sensing tool **116***a* may cease descent (i.e., movement downwards through the subsurface formation **110**).

[0063] FIG. **7** is a flow diagram of an example method **700** for acquiring seismic data (e.g., seismic data **416** of FIG. **4**) using a self-burrowing seismic-sensing tool (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**, self-burrowing seismic-sensing tool **404** of FIG. **4**) in accordance with certain embodiments. One or more components of the self-burrowing seismic-sensing tool may perform one or more steps of method **700**, for example. In certain embodiments, method **700** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **700** includes starting (block **702**), sending a signal that target destination has been reached (block **704**), waiting for capturing command (block **706**), determining whether the capturing command has been received (block **708**), recording seismic data (block **710**), waiting for stop capture command (block **714**), determining whether the stop capture command has been received (block **716**), stopping recording and triggering ascent sensor (block **718**).

[0064] Starting block **702** includes, but is not limited to, receiving an input from another component of the self-burrowing seismic-sensing tool which indicates to perform method **700**. In a non-limiting example, the input may be a command including an operation mode that triggers a data acquisition unit. In certain embodiments, the method **700** may include transmitting a signal, via a transceiver (e.g., transceiver **228**) in response to the operation mode that triggers the data acquisition unit. The signal may indicate that the target destination has been reached, for example. Method **700** may include waiting for receipt of a signal, via the transceiver, where the signal includes a command (e.g., command **402** of FIG. **4**). In response to receiving a signal, via the transceiver, method **700** determines whether the capturing command has been received at block **708**. The capturing command may indicate that the data acquisition unit is to begin one or more of receiving seismic waves, generating seismic data based on the seismic waves, or recording seismic data.

[0065] In response to a determination that the capturing command has been received, method **700** may include sending a command to the data acquisition unit to begin recording seismic data, for example. In another example, in response to the determination that the capturing command has been received, method **700** may include modifying an operation mode to indicate that the data acquisition unit is to begin recording seismic data. Recording seismic data at block **710** may include storing the seismic data to one or more of a memory of the data acquisition unit or another computer-readable medium of the self-burrowing seismic-sensing tool. Method **700** may include waiting for receipt of a signal, via the transceiver, that indicates for the data acquisition unit to stop recording seismic data. In response to receiving a signal, via the transceiver, method **700** determines whether the stop capture command has been received at block **716**. In response to a determination that the stop capture command has been received, method **700** may include modifying the operation mode to indicate to cease collection of the seismic data, to trigger ascent from the target destination to the surface location, as at block **718**, or a combination thereof.

[0066] Method **700** may include updating an operation mode to stop the data acquisition unit recording, for example. In a non-limiting example, triggering the ascent sensor may supply power to one or more of a sensor used for ascending or the burrowing device.

[0067] FIG. **8** is a flow diagram of an example method **800** for acquiring seismic data (e.g., seismic data **416** of FIG. **4**) using a self-burrowing seismic-sensing tool (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**, self-burrowing seismic-sensing tool **404** of FIG. **4**) in accordance with certain embodiments. One or more components of the self-burrowing seismic-sensing tool may perform one or more steps of method **800**, for example. In certain embodiments, method **800** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **800** includes starting (block **802**), measuring from a current location to a reference (block **804**), planning a course (block **806**), ascending on course (block **808**), comparing a current location to the course (block **810**), determining whether the self-burrowing seismic-sensing tool is on course (block **812**), updating course to the reference (block **814**), maneuvering (block **816**), determining whether the surface has been reached (block **818**), ceasing ascent (block **820**), pinging location for a retrieval system (block **822**), and triggering a retrieval process (block **824**).

[0068] Starting block **802** includes, but is not limited to, receiving an input from another component of the self-burrowing seismic-sensing tool which indicates to perform method **800**. In a non-limiting example, the input may be a command. The command may include an operation mode that triggers a sensor (e.g., first sensor **224** of FIG. **2**), the burrowing device, or a combination thereof. Triggering the sensor, the burrowing device, or the combination thereof may cause power to be supplied to one or more of a sensor used for ascending or the burrowing device, for example.

[0069] Measuring from the current location to the reference at block **804** may include determining one or measurements between the current location (e.g., the target destination) of the self-burrowing seismic-sensing tool and the reference. Method **800** may include retrieving the reference from a computer-readable medium of the self-burrowing seismic-sensing tool. The current location may be determined using the techniques described with respect to FIG. **5**, for example. In some embodiments, method **800** includes determining one or more of a distance from the current location to the reference or a difference in elevation between the current location and the reference.

[0070] Planning the course at block **806** may include determining one or more steps for the self-burrowing seismic-sensing tool to perform to navigate from the current location to the reference. In a non-limiting example, the course is a direct, or path of least distance, to ascend from the current location to the reference. In certain embodiments, method **800** may include using one or more sensors to determine a layout of a surrounding surface area. Method **800** may also include determining a route around partially buried or fully buried obstacles. Locations of the buried obstacles may be stored to a computer-readable medium of the self-burrowing seismic-sensing tool, for example. In a non-limiting example, the course may include one or more of directions, distances, coordinates, elevations, depths, or like parameters to aid in navigation. In some examples, the criteria (e.g., obstacle, action to take) for determining the course may be determined by an operator of the system, a seismic survey plan, or the like. The criteria (e.g., obstacle, action to take) for planning the course may be stored to a computer-readable medium of the self-burrowing tool or the delivery tool, for example.

[0071] In some embodiments, ascending on the course at block **808** may include actuating a burrowing device. In various embodiments, method **800** includes determining a current location of the self-burrowing seismic-sensing tool at periodic intervals. Method **800** may determine the current location using techniques described in FIG. **5**, for example. Method **800** includes comparing the current location to the course at block **810**. In a non-limiting example, method **800** includes generating an indicator in response to the comparison. For example, method **800** may generate indicators using techniques described in FIG. **5**.

[0072] In some embodiments, method **800** includes determining whether the self-burrowing seismic-sensing tool is on course at block **812** based on a result of the comparison. Method **800** may include determining whether the self-burrowing seismic-sensing tool is on course using techniques described in FIG. **5**, for example. In various embodiments, in response to a determination that the self-burrowing seismic-sensing tool is off course, method **800** includes updating the course to the reference. In a non-limiting example, method **800** may include determining one or measurements between a current location of the self-burrowing seismic-sensing tool and the reference. Method **800** may also include determining one or more steps for the self-burrowing seismic-sensing tool to perform to navigate from the current location to the reference. Method **800** may include performing one or more maneuvers at block **816** to re-position the self-burrowing seismic-sensing tool for ascent according to the updated course at block **808**.

[0073] In other embodiments, in response to a determination that the self-burrowing seismic-sensing tool is on course, method **800** includes determining whether the reference has been reached at block **818**. Method **800** includes comparing the current location to the reference to determine whether the surface has been reached, for example. In another non-limiting example, method **800** includes determining the surface has been reached using a sensor. For example, method **800** may include capturing an image of a surrounding area with an image sensor to determine whether the surface has been reached.

[0074] In various embodiments, in response to a determination that the self-burrowing seismic-sensing tool is not at the surface, method **800** includes continuing ascent according to the current course at block **808**. In response to a determination that the self-burrowing seismic-sensing tool is at the surface, method **800** may include ceasing ascent of the burrowing device. Pinging location for the retrieval system at block **822** includes transmitting a signal, via a transceiver, that includes the location. The retrieval system may be another tool. The other tool may be another self-burrowing seismic-sensing tool or a delivery tool, for example. The delivery tool may be the aerial delivery tool **118** of FIG. **1**, the land delivery tool **120** of FIG. **1**, or the delivery tool **202** of FIG. **2**, for example.

[0075] FIG. **9** is a diagram of the self-burrowing seismic-sensing tool **116***a* navigating the subsurface formation **110**, in accordance with certain embodiments. Upon receiving a command indicating that an operation mode indicates to ascend, self-burrowing seismic-sensing tool **116***a* may perform one or more measurements. In a non-limiting example, self-burrowing seismic-sensing tool **116***a* may determine a current location, for example. Self-burrowing seismic-sensing tool **116***a* may also determine a distance ("d") from the current location to the surface. The distance may be a depth through which the self-burrowing seismic-sensing tool is to burrow or a difference in elevation between the current location and the surface, for example. Self-burrowing seismic-sensing tool **116***a* may plan course **902** to navigate from the current location to the surface using the measurements. In a non-limiting example, self-burrowing seismic-sensing tool **116***a* may plan course **902** to include a first course **902***a* to route around obstacle **604** and a second course **902***b* to ascend to the surface using a direct path.

[0076] FIG. **10** is a flow diagram of an example method **1000** for acquiring seismic data (e.g., seismic data **416** of FIG. **4**) using a self-burrowing seismic-sensing tool (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**, self-burrowing seismic-sensing tool **404** of FIG. **4**), in accordance with certain embodiments. One or more components of the self-burrowing seismic-sensing tool may perform one or more steps of method **1000**, for example. In certain embodiments, method **1000** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **1000** includes starting (block **1002**), receiving sensor data (block **1004**), determining whether there is an operational error (block **1006**), determining that operations are good (block **1008**), proceeding with operations (block **1010**), determining there is an operational error (block **1012**), determining the operational error indicates an obstacle (block **1014**), determining the operational error indicates the tool is off course (block **1016**), determining the operational error indicates the tool is stuck (block **1018**), determining the operational error indicates a battery charge is below a threshold (block **1020**), maneuvering (block **1022**), and ascending (block **1024**).

[0077] Starting block **1002** includes, but is not limited to, receiving an input. In a non-limiting example, the input may be received from another tool, such as another self-burrowing seismic-sensing tool or a delivery tool (e.g., aerial delivery tool **118** of FIG. **1**, land delivery tool **120** of FIG. **1**, delivery tool **202** of FIG. **2**). The input may be one or more of target parameters (e.g., target parameters **403** of FIG. **4**) or a command (e.g., command **402** of FIG. **4**) for the self-burrowing seismic-sensing tool to begin operations, for example. The command may cause a command monitor (e.g., command monitor **406** of FIG. **4**) to determine an operation mode that triggers other components of the self-burrowing seismic-sensing tool, for example. The other components may include a sensor (e.g., first sensor **224** of FIG. **2**, second sensor **226** of FIG. **2**), a burrowing device (e.g., burrowing apparatus **232** of FIG. **2**), a power supply (e.g., power supply **230** of FIG. **2**), a navigator (e.g., navigator **408** of FIG. **4**), a burrower (e.g., burrower **410**), a data acquisition unit (e.g., data acquisition unit **412** of FIG. **4**), a system monitor (e.g., system monitor **414** of FIG. **4**), or a combination thereof. Triggering a component enables operations of the component by causing power to be supplied or sending one or more signals that cause the component to be placed in an operational state, for example.

[0078] In a non-limiting example, receiving sensor data at block **1004** includes receiving data from one or more sensors of the self-burrowing seismic-sensing tool. The sensor data may be received by one or more of the command monitor or a system monitor (e.g., system monitor **414** of FIG. **4**), for example. Method **1000** may include comparing the sensor data to one or more operational parameters. The operational parameters may include one or more ranges, thresholds, or tolerances that indicate whether the sensor data is indicative of operations in accordance with specifications (e.g., "normal operations"). The specifications may be supplied by a manufacturer of a component, an operator of the present system, a seismic survey planner, or a combination thereof. The operational parameters may be stored to a computer-readable medium of the self-burrowing seismic-sensing tool, for example. In response to a determination that the comparison indicates that the sensor data is indicative of normal operations, method **1000** includes waiting for receipt of more sensor data.

[0079] In response to a determination that the comparison indicates that the sensor data is not indicative of normal operations, method **1000** includes determining an operational error associated with one or more of the sensor data indicating operations not in accordance with specifications. In a non-limiting example, in response to a determination that the operational error indicates that an obstacle has been contacted or proximity to the obstacle has been detected or that the self-burrowing seismic-sensing tool is off course, method **1000** includes determining one or more maneuvers to perform. The one or more maneuvers may be performed using techniques described with respect to FIG. **5**, for example. Different maneuvers may be performed based on the operational error. For example, a first set of maneuvers may be performed in response to contact with an obstacle, a second set of maneuvers may be performed in response to proximity detection with the obstacle, and a third set of maneuvers may be performed in response to the self-burrowing seismic-sensing tool being off course. In another non-limiting example, in response to a determination that the operational error indicates that the self-burrowing seismic-sensing tool is stuck or that a battery is not operating normally, method **1000** includes planning a course for ascending. The course may be planned using techniques described with respect to FIG. **8**, for example.

[0080] FIG. **11** is a flow diagram of an example method **1100** for delivering a self-burrowing seismic-sensing tool (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**, self-burrowing seismic-sensing tool **404** of FIG. **4**) in accordance with certain embodiments. In certain embodiments, method **1100** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **1100** may be performed by a delivery tool (e.g., aerial delivery tool **118** of FIG. **1**, the land delivery tool **120** of FIG. **1**, or the delivery tool **202** of FIG. **2**) or a self-burrowing seismic-sensing tool capable of delivering itself and/or other self-burrowing seismic-sensing tools to a survey area, for example. Method **1100** includes starting (block **1102**), measuring target parameters to current location (block **1104**), determining whether the delivery site has been reached (block **1106**), navigating to the delivery site (block **1108**), delivering a self-burrowing seismic-sensing tool (block **1110**), determining whether the last delivery site has been reached (block **1112**), and returning to base and triggering tool operation (block **1114**).

[0081] Starting block **1102** includes, but is not limited to, receiving an input from a user, the present system, another system, or a combination thereof, which indicates the present system is to perform method **1100**. The user may use a computer system (e.g., remote computing device **134** of FIG. **1**) to input data or a command, for example. The data may be one or more of a seismic survey plan, one or more target parameters (e.g., target parameters **403** of FIG. **4**), or a combination thereof, for example. In a non-limiting example, the command may be to trigger operations of a delivery tool or the self-burrowing seismic-survey tool. In some embodiments, the input may be received from another tool. The other tool may be another self-burrowing seismic-sensing tool or another delivery tool, for example.

[0082] In some embodiments, method **1100** includes determining a current location. The current location may be received from one or more sensors (e.g., sensor **206** of FIG. **2**, first sensor **224** of FIG. **2**, second sensor **226** of FIG. **2**), for example. In another non-limiting example, the current location may be a location of a base or a retrieval site received as an input. Method **1100** also includes comparing the current location to one or more delivery sites specified by target parameters. Method **1100** includes determining a delivery site of the one or more delivery sites that is closest to, but not inclusive of, the current location. Method **1100** also includes planning a course from the current location to the delivery site of the one or more delivery sites that is closest to, but not inclusive of, the current location. Method **1100** includes navigating to the delivery site of the one or more delivery sites that is closest to, but not inclusive of, the current location based on the course.

[0083] In certain embodiments, method **1100** includes sampling the current location at periodic intervals to determine whether the delivery site has been reached. In response to a determination that the delivery site has not been reached at block **1106**, method **1100** includes navigating to the delivery site at block **1108**. In response to a determination that the delivery site has been reached at block **1106**, method **1100** includes placing a self-burrowing seismic-sensing tool associated with the delivery site at block **1110**.

[0084] In various embodiments, method **1100** includes determining whether to place the self-burrowing seismic-sensing tool at a surface location that is different than the delivery site. For example, method **1100** may include using a sensor to determine a layout of a surrounding surface area of the delivery site. Method **1100** may include determining whether the surrounding surface area indicates a first surface type (e.g., sand dunes) or a second surface type (e.g., hard rock). In response to a determination that the surrounding surface area is a first surface type, method **1100** may include placing an additional self-burrowing seismic-sensing tool having a different delivery site at the current delivery site. In response to a determination that the surrounding surface area is a second surface type, method **1100** may include placing the self-burrowing seismic-sensing tool at a second surface location that is different than the delivery site. In a non-limiting example, the criteria (e.g., surface type, action to take) for determining the placement may be determined by an operator of the system, a seismic survey plan, or the like. The criteria (e.g., surface type, action to take) for determining the placement may be stored to a computer-readable medium of the self-burrowing tool or the delivery tool, for example.

[0085] In certain embodiments, method **1100** includes determining a number of delivery sites specified by target parameters. In a non-limiting example, determining whether the last delivery site has been reached at **1106** includes determining whether self-burrowing seismic-sensing tools have been placed at the number of delivery sites. Method **1100** may include incrementing or decrementing a counter with each delivery, for example. In response to a determination that more deliveries are to be made, method **1100** also includes comparing the current location to one or more remaining delivery sites specified by target parameters. Method **1100** includes determining a delivery site of the one or more remaining delivery sites that is closest to, but not inclusive of, the current location. Method **1100** also includes planning a course from the current location to the delivery site of the one or more remaining delivery sites that is closest to, but not inclusive of, the current location. Method **1100** includes navigating to the delivery site of the one or more remaining delivery sites that is closest to, but not inclusive of, the current location based on the course.

[0086] In various embodiments, in response to a determination that the last delivery site has been reached at **1106**, method **1100** includes planning a course from the current location to a base. The base may be a remote facility (e.g., the remote facility **132** of FIG. **1**) or a control site (e.g., the control site **122** of FIG. **1**), for example.

[0087] FIG. **12** is a block diagram aerial view of a plurality of self-burrowing seismic-sensing tools **116** located within the subsurface formation **110**, in accordance with certain embodiments. Self-burrowing seismic-sensing tools **116***a*-**116***z* are herein collectively referred to as the plurality of self-burrowing seismic-sensing tools **116**. A layout **1200** of the plurality of self-burrowing seismic-sensing tools may be determined by one or more of a seismic survey plan, surface terrain of the subsurface formation **110**, or a combination thereof. To implement layout **1200**, the plurality of self-burrowing seismic-sensing tools **116** may be delivered to a surface of the subsurface formation **110** using techniques described herein.

[0088] In certain embodiments, each of the self-burrowing seismic-sensing tools **116** may be delivered along a substantially linear path. Substantially, as used herein, indicates that each of the self-burrowing seismic-sensing tools **116** are within a specified threshold distance of the linear path. The specified threshold distance may be determined by an operator of the system (e.g., system **100** of FIG. **1**, system **200** of FIG. **2**, system **400** of FIG. **4**), may be included in a seismic survey plan associated with subsurface formation **110**, input by a user (e.g., a user of the seismic modeling tool **130** of FIG. **1**) or the like. The specified threshold distance may be dependent upon geologic surface features that impede placement of one or more of the self-burrowing seismic-sensing tools **116** in a position that is exactly disposed along the linear path, for example.

[0089] In various embodiments, a delivery tool may modify one or more delivery sites associated with a first set **1202** of the plurality of self-burrowing seismic-sensing tools **116** based on a surface type of the one or more delivery sites. For example, a first delivery tool may modify the one or more delivery sites associated with the first set **1202** of the plurality of self-burrowing seismic-sensing tools **116** after determining that the surface of the subsurface formation **110** is hard rock. A second delivery tool may deliver a second set **1204** of the plurality of self-burrowing seismic-sensing tools **116** along a substantially linear path in accordance with a layout of the seismic survey plan. A third delivery tool may modify one or more delivery sites associated with a third set **1206** of the plurality of self-burrowing seismic-sensing tools **116** on a surface type of the one or more delivery sites. For example, the third delivery tool may modify the one or more delivery sites associated with the third set **1206** of the plurality of self-burrowing seismic-sensing tools **116** after determining that the surface of the subsurface formation **110** is sand. The third delivery tool may modify the delivery site of multiple self-burrowing seismic-sensing tools of the third set **1206** and deliver the third set **1206** to a single delivery site, for example. The first delivery tool may deliver a fourth set **1208** of the plurality of self-burrowing seismic-sensing tools **116** along a substantially linear path in accordance with a layout of the seismic survey plan.

[0090] In certain embodiments, in response to delivery tool completing delivery of the plurality of self-burrowing seismic-sensing tools **116**, the delivery tool transmits a signal to trigger each of the plurality of self-burrowing seismic-sensing tools **116** to burrow to a respective target destination. In some examples, in response to receiving a signal from each of the plurality of self-burrowing seismic-sensing tools **116** indicating that the respective target destination has been reached, the delivery tool transmits a signal to begin capturing seismic data. In other examples, in response to receiving a signal from each of the plurality of self-burrowing seismic-sensing tools **116** indicating that the respective target destination has been reached, the delivery tool transmits a signal to a remote computer system (e.g., control site **122** of FIG. **1**, remote computing device **134** of FIG. **1**) indicating that the plurality of self-burrowing seismic-sensing tools **116** are each at a respective target destination. The delivery tool may relay a signal from the remote computer system indicating to begin capturing seismic data to the plurality of self-burrowing seismic-sensing tools **116**.

[0091] In other embodiments, the plurality of self-burrowing seismic-sensing tools **116** transmit signals to each other while burrowing to respective target destinations. Each self-burrowing seismic-sensing tool of the plurality of self-burrowing seismic-sensing tools **116** may determine a distance to nearest tool neighbors based on the signals. One or more of the plurality of self-burrowing seismic-sensing tools **116** may plan a modified course in response to a determination that the distance to a nearest neighbor is less than a threshold distance. The threshold distance may be specified in a seismic survey plan, for example. By communicating with each other within the subsurface formation, the plurality of self-burrowing seismic-sensing tools **116** are able to coordinate to ensure optimal placement for seismic data acquisition. Additionally, the plurality of self-burrowing seismic-sensing tools **116** are able to synchronize communications to indicate the plurality of self-burrowing seismic-sensing tools **116** are at respective target destinations once a last self-burrowing seismic-sensing tool of the plurality of self-burrowing seismic-sensing tools **116** has reached its respective target destination.

[0092] FIG. **13** is a flow diagram of an example method **1300** for retrieving a self-burrowing seismic-sensing tool (e.g., self-burrowing seismic-sensing tools **116** of FIG. **1**, self-burrowing seismic-sensing tool **220** of FIG. **2**, self-burrowing seismic-sensing tool **404** of FIG. **4**) in accordance with certain embodiments. In certain embodiments, method **1300** is used by system **100** of FIG. **1**, system **200** of FIG. **2**, or system **400** of FIG. **4**. Method **1300** may be performed by a delivery tool (e.g., aerial delivery tool **118** of FIG. **1**, the land delivery tool **120** of FIG. **1**, or the delivery tool **202** of FIG. **2**) or a self-burrowing seismic-sensing tool capable of retrieving itself and/or other self-burrowing seismic-sensing tools from a survey area, for example. The tool performing the method **1300** may be referred to as a retrieval tool. Method **1300** includes starting (block **1302**), receiving a ping signal (block **1304**), measuring a current location (block **1306**), determining whether the current location is a same location as the ping location (block **1308**), traveling to the ping location (block **1310**), picking up a tool and returning to base (block **1312**), and ending (block **1314**).

[0093] Starting block **1302** includes, but is not limited to, receiving an input from a user, the present system, another system, or a combination thereof, which indicates the present system is to perform method **1300**. The user may use a computer system (e.g., remote computing device **134** of FIG. **1**) to input data or a command, for example. In a non-limiting example, the command may be to trigger operations of the retrieval tool. In some embodiments, the input may be received from another tool. The other tool may be another self-burrowing seismic-sensing tool or another delivery tool, for example.

[0094] In some embodiments, in response to receiving the ping signal at block **1304**, method **1300** includes causing the retrieval tool to exit a standby mode. In a non-limiting example, the ping signal includes a location of the self-burrowing seismic-sensing tool transmitting the ping signal. In another non-limiting example, method **1300** includes determining a location from which the ping signal originated using techniques such as measuring signal strength, pinging the self-burrowing seismic-sensing tool and measuring a response time, or other like methods. Method **1300** also includes determining a current location of the retrieval tool. The current location may be received from one or more sensors (e.g., sensor **206** of FIG. **2**, first sensor **224** of FIG. **2**, second sensor **226** of FIG. **2**), for example. In another non-limiting example, the current location may be a location of a base or a retrieval site received as an input.

[0095] In certain embodiments, method **1300** includes comparing the current location to the ping location. Method **1300** includes determining whether the current location is a same location as the ping location based on the comparison. In response to a determination that the current location is not the ping location, method **1300** also includes planning a course from the current location to the ping location. Method **1300** includes navigating to the ping location based on the course.

[0096] In various embodiments, method **1300** includes sampling the current location at periodic intervals to determine whether the ping location has been reached. In response to a determination that the ping location has not been reached at block **1308**, method **1300** includes navigating to the ping location at block **1310**. In response to a determination that the ping location has been reached at block **1308**, method **1300** includes retrieving one or more self-burrowing seismic-sensing tools at the ping location at block **1312**.

[0097] In some embodiments, in response to receiving multiple ping signals, method **1300** includes determining a ping location of the one or more ping signals that is closest to, but not inclusive of, the current location. Method **1300** also includes planning a course from the current location to the ping location of the one or more ping signals that is closest to, but not inclusive of, the current location. Method **1300** includes navigating to the ping location of the one or more ping signals that is closest to, but not inclusive of, the current location based on the course.

[0098] In certain embodiments, method **1300** includes determining whether a last retrieval site has been reached. The determination may be based on whether additional ping signals are received, whether a time threshold for receipt of a ping signal has elapsed, or other like method, for example. In response to a determination that the last retrieval site has been reached, method **1300** includes planning a course from the current location to a base. The base may be a remote facility (e.g., the remote facility **132** of FIG. **1**) or a control site (e.g., the control site **122** of FIG. **1**), for example.

[0099] The steps of methods **300**, **500**, **700**, **800**, **1000**, **1100**, **1300** may be executed by one or multiple self-burrowing seismic-sensing tools described herein. The steps of methods **300**, **500**, **700**, **800**, **1000**, **1100**, **1300** may be executed in any order and in any combination not logically prohibited and may individually be executed one or more times. Using the self-burrowing seismic-sensing tools described herein protects workers from hazardous conditions as well as prevents potential injuries from encountering natural elements. Additionally, the self-burrowing seismic-sensing tools reduce costs of a seismic survey by reducing a number of workers needed to deploy seismic-sensing tools and increasing a speed at which the seismic survey may be conducted.

[0100] In view of the foregoing structural and functional description, those skilled in the art will appreciate that portions of the embodiments may be embodied as a method, data processing system, or computer program product. Accordingly, these portions of the present embodiments may take the form of an entirely hardware embodiment, an entirely software embodiment, or an embodiment combining software and hardware, such as shown and described with respect to the computer system of FIG. **14**. Furthermore, portions of the embodiments may be a computer program product on a computer-readable medium having computer-readable program code on the medium. Any non-transitory, tangible storage media possessing structure may be utilized including, but not limited to, static and dynamic storage devices, hard disks, optical storage devices, and magnetic storage devices, but excludes any medium that is not eligible for patent protection under 45 U.S.C. § 101 (such as a propagating electrical or electromagnetic signal per se). As an example and not by way of limitation, a computer-readable storage media may include a semiconductor-based circuit or device or other integrated component (IC) (such as, for example, a field-programmable gate array (FPGA) or an ASIC), a hard disk, an HDD, a hybrid hard drive (HHD), an optical disc, an optical disc drive (ODD), a magneto-optical disc, a magneto-optical drive, a floppy disk, a floppy disk drive (FDD), magnetic tape, a holographic storage medium, a solid-state drive (SSD), a RAM-drive, a SECURE DIGITAL card, a SECURE DIGITAL drive, or another suitable computer-readable storage medium or a combination of two or more of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, nonvolatile, or a combination of volatile and non-volatile, where appropriate.

[0101] Certain embodiments have also been described herein with reference to block illustrations of methods, systems, and computer program products. It will be understood that blocks of the illustrations, and combinations of blocks in the illustrations, can be implemented by computer-executable instructions. These computer-executable instructions may be provided to one or more processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus (or a combination of devices and circuits) to produce a machine, such that the instructions, which execute via the processor, implement the functions specified in the block or blocks.

[0102] These computer-executable instructions may also be stored in computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory result in an article of manufacture including instructions which implement the function specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational blocks to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide blocks for implementing the functions specified in the flowchart block or blocks.

[0103] FIG. **14** is a block diagram of a computer system that can be employed to execute a system for analyzing ransomware threat intelligence in accordance with certain embodiments described. Computer system **1400** can be implemented on one or more general purpose networked computer systems, embedded computer systems, routers, switches, server devices, client devices, various intermediate devices/nodes or standalone computer systems. Additionally, computer system **1400** can be implemented on various mobile clients such as, for example, a personal digital assistant (PDA), laptop computer, pager, and the like, provided it includes sufficient processing capabilities.

[0104] Computer system **1400** includes processing unit **1402**, system memory **1404**, and system bus **1406** that couples various system components, including the system memory **1404**, to processing unit **1402**. Dual microprocessors and other multi-processor architectures also can be used as processing unit **1402**. System bus **1406** may be any of several types of bus structure including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. System memory **1404** includes read only memory (ROM) **1410** and random access memory (RAM) **1412**. A basic input/output system (BIOS) **1414** can reside in ROM **1410** containing the basic routines that help to transfer information among elements within computer system **1400**. In other examples, a unified extended firmware interface (UEFI) includes the basic routines that help transfer information among elements within computer system **1400**.

[0105] Computer system **1400** can include a hard disk drive **1416**, magnetic disk drive **1418**, e.g., to read from or write to removable disk **1420**, and an optical disk drive **1422**, e.g., for reading CD-ROM disk **1424** or to read from or write to other optical media. Hard disk drive **1416**, magnetic disk drive **1418**, and optical disk drive **1422** are connected to system bus **1406** by a hard disk drive interface **1426**, a magnetic disk drive interface **1428**, and an optical drive interface **1440**, respectively. The drives and associated computer-readable media provide nonvolatile storage of data, data structures, and computer-executable instructions for computer system **1400**. Although the description of computer-readable media above refers to a hard disk, a removable magnetic disk and a CD, other types of media that are readable by a computer, such as magnetic cassettes, flash memory cards, digital video disks and the like, in a variety of forms, may also be used in the operating environment; further, any such media may contain computer-executable instructions for implementing one or more parts of embodiments shown and described herein.

[0106] A number of program modules may be stored in drives and RAM **1412**, including operating system **1432**, one or more computer application programs **1434**, other program modules **1436**, and program data **1438**. In some examples, the computer application programs **1434** can include the seismic modeling tool **130** of FIG. **1**, the delivery tool **202** of FIG. **2**, or the self-burrowing seismic-sensing tool **220** of FIG. **2**, and the program data **438** can include seismic data **416** of FIG. **4**. The computer application programs **1434** and program data **1438** can include functions and methods programmed to perform the computer-implemented methods **300**, **500**, **700**, **800**, **1000**, **1100**, **1300** for a self-burrowing seismic-sensing tool, such as shown and described herein.

[0107] A user may enter commands and information into computer system **1400** through one or more input devices **1440**, such as a pointing device (e.g., a mouse, touch screen), keyboard, microphone, joystick, game pad, scanner, and the like. For instance, the user can employ input device **1440** to edit or modify settings, such as a target destination, of the seismic modeling tool **130** of FIG. **1**, the delivery tool **202** of FIG. **2**, or the self-burrowing seismic-sensing tool **220** of FIG. **2**. These and other input devices **1440** are often connected to processing unit **1402** through a corresponding port interface **1442** that is coupled to the system bus, but may be connected by other interfaces, such as a parallel port, serial port, or universal serial bus (USB). One or more output devices **1444** (e.g., display, a monitor, printer, projector, or other type of displaying device) is also connected to system bus **1406** via interface **1446**, such as a video adapter.

[0108] Computer system **1400** may operate in a networked environment using logical connections to one or more remote computers, such as remote computer **1448**. Remote computer **1448** may be a workstation, computer system, router, peer device, or other common network node, and typically includes many or all the elements described relative to computer system **1400**. The logical connections, schematically indicated at **1450**, can include a local area network (LAN) and a wide area network (WAN). When used in a LAN networking environment, computer system **1400** can be connected to the local network through a network interface or adapter **1452**. When used in a WAN networking environment, computer system **1400** can include a modem, or can be connected to a communications server on the LAN. The modem, which may be internal or external, can be connected to system bus **1406** via an appropriate port interface. In a networked environment, computer application programs **1434** or program data **1438** depicted relative to computer system **1400**, or portions thereof, may be stored in a remote memory storage device **1454**.

[0109] Embodiments disclosed herein include:

[0110] A. A self-burrowing seismic-sensing tool that includes a navigator, implemented by a processor, configured to determine a course to a target destination within a subsurface formation, the course being based on a current location received from one or more sensors, a burrower, implemented by the processor, configured to operate a burrowing device to reach the target destination based on the course, and a data acquisition unit, implemented by the processor, configured to generate seismic data based on seismic waves received at the target destination.

[0111] B. A computer-implemented method for a self-burrowing seismic-sensing tool including the steps of determining a course to a target destination within a subsurface formation from a surface location, operating a burrowing device to the target destination based on the course, and generating seismic data based on seismic waves received at the target destination.

[0112] C. A computer-readable medium storing computer-executable instructions, which, when executed by a processor, causes the processor to perform steps to determine a course to a target destination within a subsurface formation, the course based on a current location received from one or more sensors, operate a burrowing device to the target destination based on the course, and collect seismic data based on seismic waves received at the target destination.

[0113] Each of embodiments A, B, and C may have one or more of the following additional elements in any combination: Element 1: further comprising a command unit, implemented by the processor, configured to receive one or more commands or operational errors and to determine one or more operation modes based upon the one or more commands or operational errors. Element 2: wherein the burrower causes the burrowing device to descend within the subsurface formation in response to the one or more operation modes indicating descent, and wherein the burrower causes the burrowing device to ascend within the subsurface formation in response to the one or more operation modes indicating ascent. Element 3: wherein the data acquisition unit acquires data in response to the one or more operation modes indicating to begin seismic data acquisition, and wherein the data acquisition unit ceases acquiring data in response to the one or more operation modes indicating to cease seismic data acquisition. Element 4: wherein the command unit causes a transceiver to transmit a signal in response to the one or more operation modes indicating the self-burrowing seismic-sensing tool is waiting for retrieval. Element 5: further comprising a wireless communication unit configured to facilitate underground communication with wireless communication units of adjacent self-burrowing seismic-sensing tools.

[0114] Element 6: further comprising receiving an indication to cease collection of the seismic data, and ascending from the target destination to the surface location. Element 7: further comprising descending from the surface location to the target destination via a first course, and ascending from the target destination to the surface location via a second course, wherein the first course and the second course are different courses. Element 8: further comprising receiving an indication of an operational error, determining that the operational error indicates a navigational error, and performing a maneuver to correct for the navigational error. Element 9: further comprising determining that the operational error indicates a system error, determining one or more measurements between a current location and the surface location, and determining the second course to navigate from the current location to the surface location. Element 10: further comprising determining one or more measurements between the surface location and the target destination, and determining the course based upon the one or more measurements. Element 11: further comprising determining a current location within the subsurface formation at periodic intervals, comparing the current location determined at each periodic interval to the course, and re-positioning the burrowing device based on the comparison indicating that the current location deviates from the course by a specified threshold. Element 12: further comprising comparing the current location determined at each interval to the target destination, ceasing descent based on the comparison indicating that the current location is the target destination, and triggering collection of the seismic data. Element 13: further comprising determining one or more measurements between the target destination and the surface location, determining a second course to navigate from the target destination to the surface location, and ascending from the target destination to the surface location based on the second course. Element 14: further comprising comparing the current location determined at each interval to the second course, and re-positioning based on the comparison indicating that the current location deviates from the second course by the specified threshold. Element 15: further comprising comparing the current location determined at each interval to the surface location, ceasing ascent based on the comparison indicating that the current location is the surface location, and triggering retrieval of the self-burrowing seismic-sensing tool. Element 16: further comprising receiving the target destination, and navigating to a delivery site associated with the target destination.

[0115] Element 17: wherein the processor is further operable to determine one or more operation modes based upon one or more commands or operational errors received, cause the burrowing device to descend in response to the one or more operation modes indicating descent, cause the burrowing device to ascend in response to the one or more operation modes indicating ascent, and cause a transceiver to transmit a signal in response to the one or more operation modes indicating that a self-burrowing seismic-sensing tool is waiting for retrieval.

[0116] By way of non-limiting example, exemplary combinations applicable to A, B, and C include: Element 1 with Element 2; Element 1 with Element 3; Element 1 with Element 4; Element 6 with Element 7; Element 7 with Element 8; Element 7 with Element 9; Element 10 with Element 11; Element 11 with Element 12; Element 12 with Element 13; Element 13 with Element 14; and Element 14 with Element 15.

[0117] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, for example, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "contains", "containing", "includes", "including," "comprises", and/or "comprising," and variations thereof, when used in this specification, specify the presence of stated features, integers, blocks, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, blocks, operations, elements, components, and/or groups thereof.

[0118] Terms of orientation are used herein merely for purposes of convention and referencing and are not to be construed as limiting. However, it is recognized these terms could be used with reference to an operator or user. Accordingly, no limitations are implied or to be inferred. In addition, the use of ordinal numbers (e.g., first, second, third, etc.) is for distinction and not counting. For example, the use of "third" does not imply there must be a corresponding "first" or "second." Also, as used herein, the terms "coupled" or "coupled to" or "connected" or "connected to" or "attached" or "attached to" may indicate establishing either a direct or indirect connection, and is not limited to either unless expressly referenced as such.

[0119] While the description has described several exemplary embodiments, it will be understood by those skilled in the art that various changes can be made, and equivalents can be substituted for elements thereof, without departing from the spirit and scope of the invention. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation, or material to embodiments of the description without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments described, or to the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, or component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative.

What is claimed is:

1. A self-burrowing seismic-sensing tool, comprising:

a navigator, implemented by a processor, configured to determine a course to a target destination within a subsurface formation, the course being based on a current location received from one or more sensors;

a burrower, implemented by the processor, configured to operate a burrowing device to reach the target destination based on the course; and

a data acquisition unit, implemented by the processor, configured to generate seismic data based on seismic waves received at the target destination.

2. The self-burrowing seismic-sensing tool of claim **1**, further comprising a command unit, implemented by the processor, configured to receive one or more commands or operational errors and to determine one or more operation modes based upon the one or more commands or operational errors.

3. The self-burrowing seismic-sensing tool of claim **2**, wherein the burrower causes the burrowing device to descend within the subsurface formation in response to the one or more operation modes indicating descent, and wherein the burrower causes the burrowing device to ascend within the subsurface formation in response to the one or more operation modes indicating ascent.

4. The self-burrowing seismic-sensing tool of claim **2**, wherein the data acquisition unit acquires data in response to the one or more operation modes indicating to begin seismic data acquisition, and wherein the data acquisition unit ceases acquiring data in response to the one or more operation modes indicating to cease seismic data acquisition.

5. The self-burrowing seismic-sensing tool of claim **2**, wherein the command unit causes a transceiver to transmit a signal in response to the one or more operation modes indicating the self-burrowing seismic-sensing tool is waiting for retrieval.

6. The self-burrowing seismic-sensing tool of claim **1**, further comprising a wireless communication unit configured to facilitate underground communication with wireless communication units of adjacent self-burrowing seismic-sensing tools.

7. A computer-implemented method for a self-burrowing seismic-sensing tool, comprising:

determining a course to a target destination within a subsurface formation from a surface location;

operating a burrowing device to the target destination based on the course; and

generating seismic data based on seismic waves received at the target destination.

8. The computer-implemented method of claim **7**, further comprising:

receiving an indication to cease collection of the seismic data; and

ascending from the target destination to the surface location.

9. The computer-implemented method of claim **8**, further comprising:

descending from the surface location to the target destination via a first course; and

ascending from the target destination to the surface location via a second course, wherein the first course and the second course are different courses.

10. The computer-implemented method of claim **9**, further comprising:

receiving an indication of an operational error;

determining that the operational error indicates a navigational error; and

performing a maneuver to correct for the navigational error.

11. The computer-implemented method of claim **9**, further comprising:

determining that the operational error indicates a system error;

determining one or more measurements between a current location and the surface location; and

determining the second course to navigate from the current location to the surface location.

12. The computer-implemented method of claim **7**, further comprising:

determining one or more measurements between the surface location and the target destination; and

determining the course based upon the one or more measurements.

13. The computer-implemented method of claim **12**, further comprising:

determining a current location within the subsurface formation at periodic intervals;

comparing the current location determined at each periodic interval to the course; and

re-positioning the burrowing device based on the comparison indicating that the current location deviates from the course by a specified threshold.

14. The computer-implemented method of claim **13**, further comprising:

comparing the current location determined at each interval to the target destination;

ceasing descent based on the comparison indicating that the current location is the target destination; and

triggering collection of the seismic data.

15. The computer-implemented method of claim **14**, further comprising:

determining one or more measurements between the target destination and the surface location;

determining a second course to navigate from the target destination to the surface location; and

ascending from the target destination to the surface location based on the second course.

16. The computer-implemented method of claim **15**, further comprising:

comparing the current location determined at each interval to the second course; and

re-positioning based on the comparison indicating that the current location deviates from the second course by the specified threshold.

17. The computer-implemented method of claim **16**, further comprising:

comparing the current location determined at each interval to the surface location;

ceasing ascent based on the comparison indicating that the current location is the surface location; and

triggering retrieval of the self-burrowing seismic-sensing tool.

18. The computer-implemented method of claim **7**, further comprising:

receiving the target destination; and

navigating to a delivery site associated with the target destination.

19. A computer-readable medium storing computer-executable instructions, which, when executed by a processor, causes the processor to:

determine a course to a target destination within a subsurface formation, the course based on a current location received from one or more sensors;

operate a burrowing device to the target destination based on the course; and

collect seismic data based on seismic waves received at the target destination.

20. The computer-readable medium of claim **19**, wherein the processor is further operable to:

determine one or more operation modes based upon one or more commands or operational errors received;

cause the burrowing device to descend in response to the one or more operation modes indicating descent;

cause the burrowing device to ascend in response to the one or more operation modes indicating ascent; and

cause a transceiver to transmit a signal in response to the one or more operation modes indicating that a self-burrowing seismic-sensing tool is waiting for retrieval.

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