Recent Trends of Exploration Geophysics 
and Improvements in Data Acquisition Technology

Hiromasa Shima

Group Management Headquarters, OYO Corporation

Market needs for exploration geophysics are analyzed. Market movements from expert market to non-expert market, from upstream of a project to downstream of it, as well as the unchanging importance of technical differentiation are suggested. The trends of exploration geophysics influenced by recent general technical advancements are reviewed. Advanced electronics, software and information technology have enabled the acquisition and interpretation of large datasets. The general public is expecting more with exploration geophysics, and is impatient with uncertainty. To effectively improve exploration geophysics, geophysical methodology including a way to optimize the performance and cost is discussed. To efficiently achieve a quality result, tips to improve the quality of datasets and quality of analysis are also discussed. These reviews and studies are summarized into the development goals of geophysical instruments. Finally, some recent instrument developments conducted by colleagues of the author are introduced. It seems exploration geophysics has a large potential of expanding its application and resulting market. Systematic development based on logical methodology can guide the efficient development of new geophysical instruments.

1. Changes in needs and seeds

Social and economic systems are changing. Technologies are also changing. While several new technologies have been applied to geophysics, application areas of geophysics don't seem to be expanding. Geophysics has been known as a tool used to explore subsurface resource in business and used to investigate natural disasters like earthquake and volcano eruption in academics. Because relatively small number of people actually know geophysics, simple incorporation of new technologies doesn't expand the geophysical market. How can we understand changes in social needs and utilize the new technologies to improve geophysics, and eventually grow the market for it?

(1) Substantial needs

It may be possible to classify needs into two categories: substantial needs and additional (peripheral) needs. Each of them consists of an unchanging part and changing part. In the substantial needs of geophysics, unchanging ones are very primitive desires –“want to see unseen” and “want to see more details”. This may be interesting for majority of people. However, application of this kind of technology with economical return is limited, thus this technology hasn’t been widely used so far.

Major application of geophysics has changed as society is developed and matured. In the development stage, finding underground resources and energy has the highest priority. As the society matures, the importance of protecting the environment increases.

In a same application, as technology is improved, use of geophysics has expanded from beginning stage to following stage. As an example, for underground resource utilization, geophysics is first used to find it, then used to help development and eventually applied to production (reservoir monitoring during production is an emerging market). These concepts are summarized in Fig.1.

![Figure 1 Breakdown of substantial needs.](image-url)
(2) Additional needs

Unchanging parts of the additional needs are simple, as shown in Fig. 2. They are “the more, the better” type desires. However, how much customers will pay for these are uncertain. Changing parts of additional needs reflect changes in society and sense of value. While these are convenient for customers and necessary to adapt to today’s changing world, they don’t necessarily expand the range of application and market size.

![Figure 2: Breakdown of additional needs.](image)

(3) Market size

I tried to summarize the applications of geophysics and their estimated market size. In this analysis, geophysics includes both surface and borehole geophysics. It is no doubt that the market size of energy (mainly oil and gas) exploration market is the largest market (100 times larger than many others). Mineral exploration market follows it (10 times larger than others). At this point in time, most of the newer applications for matured society have significantly smaller market size.

Market size is a simple product of price and volume. While the number of potential customers in non-expert markets and in developing countries is huge, few of them know geophysics. In addition to that, the price they are willing to pay for geophysics is very low. We need to increase the value of geophysics and develop the market in these market segments to make Fig. 4 true.

![Figure 4: Future market size.](image)

2. Trends of geophysics

(1) Advances in general technology

Advances in electrical hardware is continuously progressing day and night. We can now obtain large memory, high performance A/D and FPGA for reasonable cost. Pre-assembled PC boards are making geophysical instrument controllers a commodity. Web networking and cloud computing are changing our legacy way of data analysis and data management. Revolutions in mechanics and robotics are changing our way of data acquisition. All these make it easier and more economical to acquire, store, and manage a large volume of data.

![Figure 5: Trends in general technology.](image)
(2) Advances in applications
In general, a larger amount of data and higher quality data provide higher accuracy and resolution. Efficient data acquisition with accurate timing and positioning allow for feasible 3D and 4D exploration. Smarter software and combination of instruments and software is making geophysics easier to use and understand. These are recent driving forces to improve geophysics as summarized in Fig. 6.

3. Methodology for new exploration geophysics
In order to take advantage of mentioned trends and to develop new geophysics, we should clearly understand new needs for geophysics and review legacy geophysical methodology, then design a new geophysical methodology based on the new electronic, mechanical and information technologies available.

(1) Geophysical methodology
In geophysical methodology, for example, to achieve clearer subsurface image, we first study potentially available geophysical phenomena (information source) and efficient ways to extract the information from data. Once we define the necessary dataset, we design effective source-receiver geometry, a required set of sensing components, and an appropriate combination of sensors. Then we finally define required specification of each sensor as shown in Fig 7.

(2) Conversion from needs to design specification
Besides the above mentioned sensor specification, we have to define the specification of the dataset as well as the specification of data processing and analysis, details of which are discussed in the following chapter.

Once geophysical specifications are defined by the geophysical methodology, then we have to convert such geophysical specifications into electrical, mechanical and firmware specifications through appropriate methodologies for such technical areas.

In the methodological study, usability, reliability and economics are always key issues we have to take into serious consideration.

(3) Compromise between performance and cost
Performance of exploration geophysics is a result of a process shown in Fig. 9. To improve any of these processes we usually have to pay additional cost.
How is the cost justified? The cost (e.g. price of an instrument, software, or service) must be smaller than added value. The added value is the product of performance and its lifetime discounted by appropriate discount rate as shown equations (1) and (2) in the simplest case.

\[ \text{Added value} > \text{Price} \quad (1) \]

\[ \text{Added value} \propto \sum_{n=1}^{\text{Lifetime}} \text{Performance} \cdot (1 + DR)^{n-1} \quad (2) \]

where DR is discount rate.

For example, if an instrument can make “X” dollars for “Y” years, and if a discount rate applied in the industry is “Z”%, the maximum price of the instrument is estimated by equation (2).

4. Data acquisition and data analysis

(1) Quality of data acquisition

Data acquisition is designed to maximize the quality of a dataset within an appropriate acquisition cost. The quality of the dataset is a function of the amount of the information the dataset contains and cost of acquisition (usually financial and time costs).

There are several ways proposed to measure the amount of information of the dataset. It should be noted that any information that will not be used in subsequent processing and analysis is meaningless.

Information of a datum is a function of physical phenomena measured, position and time/timing of the measurement point, and error of the datum.

\[ \text{Information of datum} \approx f(\text{MP, P, T, E}) \quad (3) \]

where MP is measured physical phenomena, P is position, T is time, and E is error of datum.

Independency between data is a very important factor to estimate the information of the dataset as a whole. In Fig 10, A1, A2, and A3 in Dataset-A have very different viewpoints, thus each of them has independent information. In Dataset-B, all B1 through B10 have very similar viewpoints and very dependent information. In this case, Dataset-A has more information with fewer data points. Smaller number of data reduces time of both data acquisition and data analysis. Therefore, the quality of Dataset-A is much better than Dataset-B.

4. Data acquisition and data analysis

(2) Quality of data analysis

Data processing and analysis are designed to maximize their quality within an appropriate cost.

Quality of data processing and analysis depends on how well the processing and analysis convert the information of data from data space to model space.

Generally speaking, the error in accuracy and the error in resolution contradict each other. Shima, 1992, proposed a way to optimize them so that total error of accuracy and resolution can be minimized (See Fig. 11a). In most of the inversion schemes that use small cells to represent underground structures, cell size is another important factor that influences the error in the inverted image (See Fig. 11b).

We have to design data analysis to minimize the total error in the inverted subsurface image.

<table>
<thead>
<tr>
<th>Data set</th>
<th>Data point</th>
<th>Amount of info</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>Low</td>
<td>Very low</td>
</tr>
</tbody>
</table>
My colleagues are developing new geophysical instruments with consideration of above mentioned market analysis and geophysical methodology. Our recent goals of development are summarized in Table 2. Four examples are introduced to show our activities.

<table>
<thead>
<tr>
<th>Inputs from market</th>
<th>Inputs from technology</th>
<th>Development target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product differentiation</td>
<td>Unique technology</td>
<td>High-performance sensor</td>
</tr>
<tr>
<td>Clearer image</td>
<td>Large dataset</td>
<td>Efficient data acquisition &amp; analysis</td>
</tr>
<tr>
<td>Non-expert user</td>
<td>All-in-one, Friendly GUI</td>
<td>Application specific solution (hardware + software)</td>
</tr>
<tr>
<td>Upstream to down stream</td>
<td>High-resolution, Data fusion</td>
<td>Small system, Digital network</td>
</tr>
</tbody>
</table>

(1) GPR solution

Engineers of GSSI (Geophysical Survey Systems Inc.) have developed an application-specific and easy-to-use all-in-one GPR (Ground Penetrating Radar) system, which is specialized for concrete inspection. The system can be operated by one thumb for more than three hours without changing an internal battery. Data obtained are filtered, migrated and displayed on the screen after simple procedures. Automatic rebar/pipe detection feature is implemented. This easy-to-use and understand cost effective system has been developing a concrete structure inspection market where most users are non-expert with limited knowledge of geophysics.

(2) High resolution marine seismic system

Engineers of Geometrics Inc. have commercialized an ultra-high resolution marine seismic streamer system under cooperative relationship with P-cable consortium. P-cable is the unique system to efficiently and cost-effectively deploy very short offset streamer cables for ultra-high resolution 3D exploration. P-cable can tow 6 to 24 streamers usually at 6.25 meter or 12.5 meter cable separation. Each streamer can contain 8 to 32 hydrophones at usual interval of 3.125 meter. Newly developed slim digital streamer (41mm in diameter) realizes excellent noise level and operational performance.
The system has made the high resolution marine seismic survey affordable to a wider range of users in oil and gas industry as well as in academics and geo-engineering industry.

(3) Magnetic sensor
Engineers of Geometrics Inc. have been developing MFAM (Micro Fabricated Atomic Magnetometer) under the initiative of several US government research programs. The goals of MFAM development is significant reduction of volume (from 250cc to 1cc) and power consumption (from 10 W to 0.2W) without losing sensitivity (a few pT sensitivity under earth magnetic field) and accuracy. Thanks to these small size and power consumption, Geoemtrics recently successfully tested a 10 by 10 array (100 of 2mm cubic cells). This significantly small and low power consumption magnetic sensor is expected to develop a wide range of new applications.

![Figure 14 Micro Fabricated Atomic Magnetometer (MFAM).](image)

Figure 14 Micro Fabricated Atomic Magnetometer (MFAM). (a) Geometrics’ standard cesium vapor magnetic sensor, (b) early days MFAM engineering model, (c) Test pit at Geometrics for testing a 10 x 10 array of 2mm cubic cells.

(4) Seismic sensor
Engineers of Kinematics Inc. have been developing micromechanical seismometers under the initiative of several US government research programs. Prototypes have demonstrated noise levels of 3-4ng/√Hz and the target noise performance is <1ng/√Hz which would place the sensor noise below the New Low Noise Model from 20 seconds to 30 Hz. The small size, low weight, and low power consumption of these devices makes them very attractive for a variety of geophysical measurements.

![Figure 15 Micromechanical Seismometer.](image)

Figure 15 Micromechanical Seismometer. (a) schematic view in cross section, (b) packaged micro-seismometer, (c) die assembled into magnetic circuit and pre-Amp, (d) silicon spring.

6. Conclusion
I have presented a framework for analyzing the forces and trends acting on the exploration geophysics, especially on its instrumentation. Changes from expert market to non-expert market, from upstream of a project to downstream of it, as well as the unchanging importance of technical differentiation are suggested. Advanced technologies have enabled the acquisition and interpretation of large datasets. To effectively improve exploration geophysics, geophysical methodology including ways to optimize the performance and cost as well as to improve the quality of datasets and analysis are discussed. I have also shown examples of new instrumentation that is positioned to apply technical advances to the emerging trends and opportunities. It seems exploration geophysics has a large potential of expanding its application and resulting market.

References