The advanced geological researches and fundamental national land information

— Development process of the Geological Map of Japan 1:50,000 —

Makoto Saito

[Translation from *Synthesiology*, Vol.2, No.4, p.321-331 (2009)]

The Geological Map of Japan 1:50,000 shows fundamental national land information of the subsurface materials of the district, and is multifariously used for resources development, disaster prevention, siting of industrial activities, environment protection, and as the geological standard of the district. It is important basic information for understanding natural environments scientifically and is essential information for the sustainable development of Japan. While geological maps mostly made by universities or companies are for understanding specifically interesting strata or rocks, the 1:50,000 geological maps made by GSJ, AIST comprehensively integrate research results of all strata and rocks in the district and explain the geological evolution of the district. There has never been any paper describing the process in developing the 1:50,000 geological map, which integrates geological research for the district. The author shows his own development process with the 1:50,000 geological maps as examples.

Keywords **:** Geological map, 1:50,000, integration, geology, process, Tomochi

1 Introduction

Geological maps provide fundamental information about the Earth. They show the type, age of formation, configuration, and interrelationships of the rocks beneath vegetation and surface soil. In Japan, the Geographical Survey Institute (Ministry of Land, Infrastructure, Traffic and Tourism) is responsible for topographic mapping of the onshore land surface and landlocked bays and publishes topographic contour maps. The Hydrographic and Oceanographic Department of the Japan Coast Guard is responsible for mapping the ocean floor and publishes bathymetric charts. The Geological Survey of Japan (GSJ) looks beneath the surface of the Earth and gathers information to publish geological maps. These geological maps provide fundamental data for many uses in Japan, including resource exploration, disaster prevention, civil engineering, environmental protection, and academic research.

The basic geological maps published by GSJ are rectangular Geological Map of Japan (GMJ) sheets, which are defined by a grid of longitude and latitude, and are mostly at scales of 1:50,000 or 1:200,000. Maps at 1:50,000 scale are prepared from original geological survey data, whereas those at 1:200,000 scale cover a wider area and are created by sorting, selecting, and integrating (the process of compilation) the geological information from GMJ 1:50,000 sheets and other sources.

There is a variety of strata and rocks within most rectangular map sheet areas. In the past, one geologist could complete the survey for a GMJ 1:50,000 sheet. However, recent advances in the field of geology and geological mapping mean that the cooperation of several geologists with specialized knowledge is needed. Further, greater geological accuracy and professional result of research of individual rocks and strata are demanded than was the cases in the past. All strata and rocks must be unambiguously integrated to provide a plausible geological evolution of the area mapped.

In this paper, I discuss the synthesis and production of a GMJ 1:50,000 sheet from original geological survey data using as an example the Tomochi 1:50,000 sheet in central Kyushu (Figs. 1 and 6), the most geologically complicated GMJ 1:50,000 sheet that has been published recently. I also discuss how GMJ sheets are used for the benefit of Japanese society.

2 Our research objectives

The overall objective for our geological mapping of the GMJ 1:50,000 sheet was to apply state-of-the-art geological concepts to new field survey data. Other objectives were to clarify the relationship of the rocks of each GSJ 1:50,000 sheet to the wider regional geology and to create a new standard for production of 1:50,000 geological maps in each region.

Production of the Tomochi sheet is also part of a plan to methodically increase the GMJ 1:50,000 scale coverage to eventually cover the whole of the Japanese Archipelago. Even if new 1:50,000 mapping does not produce dramatically different conclusions to past mapping, integration of new survey data clarifies the broad regional geology and is an important result of the GMJ program, which also has considerable significance for Japanese society.

Institute of Geology and Geoinformation, AIST Tsukuba Central 7, 1-1-1 Higashi, Tsukuba 305-8567, Japan E-mail : saitomkt@ni.aist.go.jp

Original manuscript received September 11, 2009, Revisions received October 27, 2009, Accepted November 2, 2009

2.1 Previously known geology of the area

The Tomochi 1:50,000 sheet includes the mountainous region of Gokanosho in Izumi-mura village (currently Yashiro-shi) said to have been the new home of fleeing warriors of the Heike clan. The sheet is also upstream of the Itsukimura area in the Kumamoto Prefecture of central Kyushu, which is known for the “Itsuki No Komori Uta” (Itsuki Lullaby). It is characterized by a complicated distribution of diverse strata and rocks in an area of steep mountain terrain that makes field survey work difficult (Fig. 1). The sheet area (23.5 km east–west, 18.5 km north–south, surface area approximately 435 km^2) contains the following geological elements:

1) accretionary complexes in which the rocks of a subducting oceanic plates have been accreted onto continental margins;
2) serpentinite including Paleozoic rocks;
3) metamorphic rocks that have been subjected to high temperatures or pressures;
4) granitic rocks that represent solidified felsic magma rich in SiO_2;
5) continental shelf deposits;
6) pyroclastic flow deposits erupted from volcanoes (Mt. Aso and others).

Almost all of the rock types known to exist in the Japanese Archipelago are found in the Tomochi sheet area. Because we expected the geology to be extremely complicated, we used four researchers with specific but different areas of expertise for our field survey, and we aimed at new results for each rock and strata. No previous geological mapping of the area incorporated the principles of plate tectonics, so the creation of a geological map based on plate tectonics (e.g., one that identifies the rocks of the accretionary complexes) was an important objective.

2.2 Regional geology and previous geological interpretation

The area that lies on the Pacific Ocean side of the Japanese Archipelago from Kyushu to the Kanto Mountains is known as the Outer Zone of Southwest Japan. Within this zone there is a complicated distribution of accretionary complexes formed by subduction of oceanic crust during the Jurassic (200 million to 145 million years ago), strata of Silurian to Devonian age (440 million to 360 million years ago), Permian to Cretaceous (300 million to 65 million years ago) shallow-marine deposits (and some terrestrial deposits), and serpentinites and other metamorphic and plutonic rocks.

2.3 Previous geological interpretations

The classification of the rock formations of the Jurassic accretionary complex and their relationship with other formations is confused. Individual researchers have developed different classification systems. For example, rock

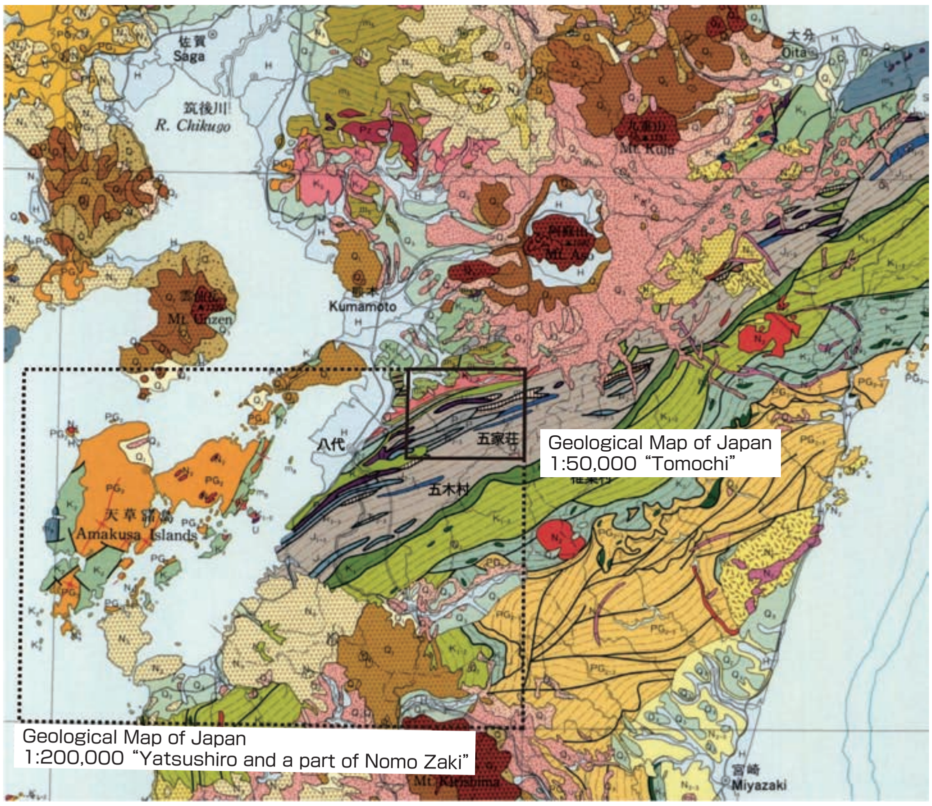

Fig. 1 Location of GMJ 1:50,000 Tomochi sheet (solid rectangle) in relation to the GMJ Yatsushiro and part of the Nomo Zaki 1:200,000 sheet (dashed rectangle)
The base map is the Geological Map of Japan 1:1,000,000 3rd Edition[1].

formations other than the Jurassic accretionary complex have in some cases been called the Kurosegawa Tectonic Zone. Other rock formations have been divided into three belts: the Southern and Northern Chichibu Belts, composed of Jurassic accretionary complexes, and the Central Chichibu Belt including other rock formations. Moreover, in the early 1990s, it was believed that the rocks on Shikoku composed of serpentinite and other metamorphic rocks (components of the so-called Kurosegawa Belt) overlie the Jurassic accretionary complex above a low-angle thrust fault[2][3].

2.4 Our specific geological objectives

In the Tomochi district, in addition to the Jurassic accretionary complex, serpentinites and other metamorphic rocks, Silurian to Devonian sedimentary rocks, and Permian to Cretaceous shallow-marine sediments are widely distributed. Investigation of the regional relationships of the previously identified geological entities was a specific objective of our mapping, with the aim of clarifying the classification of the rocks of the Jurassic accretionary complex and other formations, thus resolving the major contentious issues of previous interpretations of the geological evolution of the Japanese Archipelago.

There were many other interesting issues to investigate, such as the geological structure of Cretaceous shallow-marine deposits, the relationship of Cretaceous metamorphic rocks to the surrounding rocks, and the evolutionary history of Cretaceous high-temperature metamorphic rocks. Another specific objective was to clarify these issues so that our mapping of the Tomochi sheet would create a standard to be used in further investigations of the regional geology over a wide area surrounding the Tomochi sheet.

3 Societal value of the GMJ program

A discussion of the societal value of geological maps such as the GMJ 1:50,000 series has been published by AIST[4], and that of geological maps in general has been considered by the United States Geological Survey[5][6].

Products of the GMJ 1:50,000 series have many uses. Some of these are:

1) civil engineering and construction (e.g., construction of roads, dams, power stations, bridges, and commercial and residential buildings);
2) disaster prevention (e.g., information on active faults, volcanic eruptions, flooding of rivers, ground subsidence, landslides, unstable ground);
3) resource development (e.g., information about oil, natural gas, coal, geothermal energy, hot springs, groundwater, minerals such as metals and clay, dimension stone and aggregate);

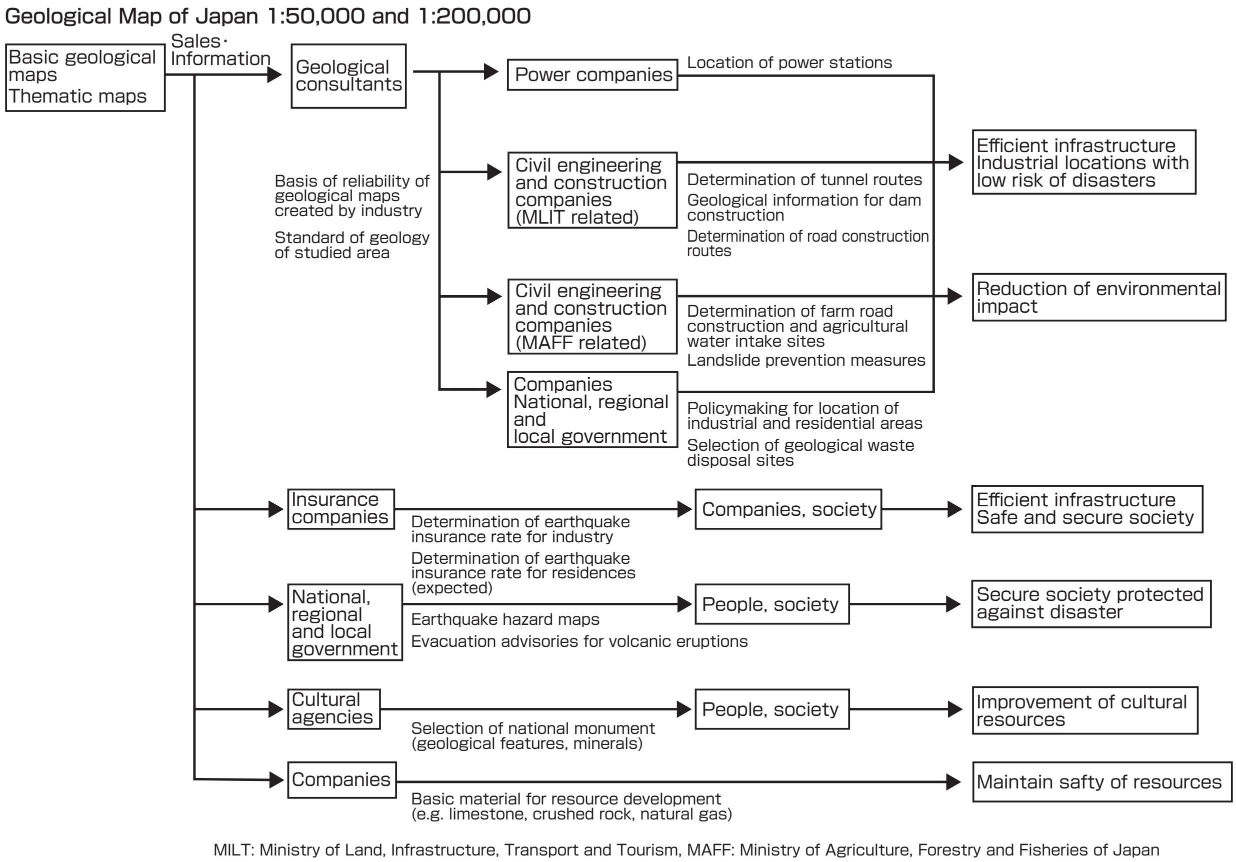

Fig. 2 Uses of GMJ products and outcomes[4].

4) environmental matters (e.g., groundwater flow, underground disposal of radioactive and hazardous waste);
5) academic information for investigation of regional geological evolution (e.g., the process of formation of the Japanese Archipelago, changes in the environment, compilation of seamless geological maps);
6) provision of a standard for investigating the detailed geology of Japan at the district level.

In Japan, geological maps have been produced since the mid-1800s. Initially, the main objective was the development of domestic resources. During the period of rapid Japanese economic growth in the 1950s and 1960s, identification of limestone resources suitable for use in cement was given high priority. Today, although one of the major emphases is on defining resources such as stone for use as aggregate and identifying hot springs, geological maps are used to satisfy other basic and diverse societal needs. They provide information that can be used to mitigate damage caused by earthquakes and volcanic eruptions. They can be used to identify unstable ground conditions, to determine safe locations for industry (e.g., nuclear power stations), and to select disposal sites for waste materials. They are important tools for geological consultants who need to understand the local geology in the areas of their projects. Recently, geological information has been used as a resource for tourism. Geoparks have been established throughout Japan where people can visit interesting geological formations. Geological maps also provide companies with basic information for use in business continuity plans that can minimize disruptions to their business activities following natural disasters. The effects of the use of geological maps described above can be divided into two categories: those that add to the economy (e.g., identification of resources), and those that reduce costs within the economy (e.g., reduction of the costs of disaster recovery).

Each GMJ 1:50,000 sheet is not initiated with any one of the above specific uses in mind. The decision to survey the Tomochi 1:50,000 sheet was made with the primary objective of developing a comprehensive and accurate representation of the geology of the entire district. However, the knowledge and information gained from the survey are used directly by society or through specific-purpose geological maps developed from the survey data (Fig. 2). The former Technology Information Department at AIST stated that the characteristic outcome of geological maps "fans out widely from the Geological Survey of Japan"[7].

4 Methodology for creating the GMJ

The development of a geological map is not a deductive research project. No experiment is performed to confirm a hypothesis. It uses an inductive method, where truth is determined from observations of strata and rocks exposed in a particular area. During a geological survey, a geological model of the area is created in the researcher's mind on the

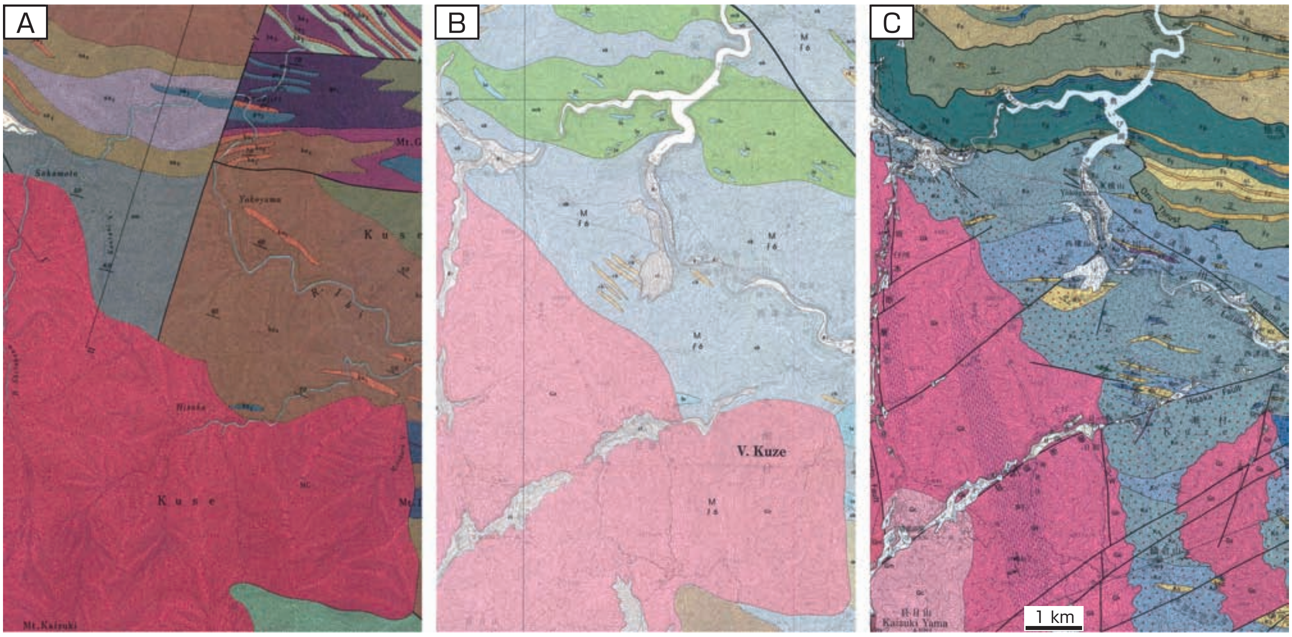

Fig. 3 Example of the changes in the geological map.
Example of GMJ 1:50,000 "Yokoyama" district [revised from Reference 8].
A: Geological map created in the 1960s[9]
The concept of an accretionary complex was not incorporated.
B: Surface geological map created in the 1990s[10]
This map was created without sufficient time for an adequate survey.
C: GMJ Yokoyama 1:50,000 sheet published in 2000[11]

basis of observations, and the model is progressively updated as the survey proceeds. The accuracy of the information gathered in the field is heavily dependent on the skills and knowledge of the researcher conducting the survey. Careful and knowledgeable observation in the field is the most important process in the creation of a geological map, and also can yield new discoveries.

New maps produced using more advanced methods to resurvey previously mapped areas may produce considerable changes. Improved accuracy may be the result of finding new areas of outcrop (places where rocks are exposed at the surface), or because observation methods have improved and geological theory has advanced since the original survey. It is similar to the case where noise may be reduced due to the advancement of the measuring technology and therefore precise measurement becomes possible. This is clearly shown by comparison of previous geological maps of a particular area with a current geological map (Fig. 3).

Therefore, the GMJ 1:50,000 "Tomochi" was expected to become the standard for determining the strata and rocks based on the latest geological knowledge of this district. Also, we employed the following three research methods to obtain advancements in this field as indicated in the research objective.

1) The researchers in charge collected the geological information based on the latest geological findings, and completed the geological map of the district in charge. Taking the example of the strata and rocks of the accretionary complex that the author was in charge, it is currently accepted that structures within an accretionary complex are nearly horizontal and are controlled largely by thrust faults. Within the complex, the rocks above thrust faults are older than those underlying the faults (Fig. 4). We used age data from abundant microfossils (plankton) to establish that the sediments above the thrust faults were older than those below it. Current geological theory also suggests that an accretionary complex in this district should be overlain by a rock sequence that includes serpentinite. During our field survey, we identified the rocks overlying the accretionary complex and noted their structural relationship with the accretionary complex (Fig. 5).

2) Older strata and rocks in their present position have been affected by repeated later episodes of folding and faulting. Therefore, for example, if the deformation that occurred after the formation of an accretionary complex is recognized, by comparing the structure within the complex with the present geological structure it is possible to understand the deformation that occurred both before and during the formation of the accretionary complex. We shared the geological survey data collected by the four researchers at the

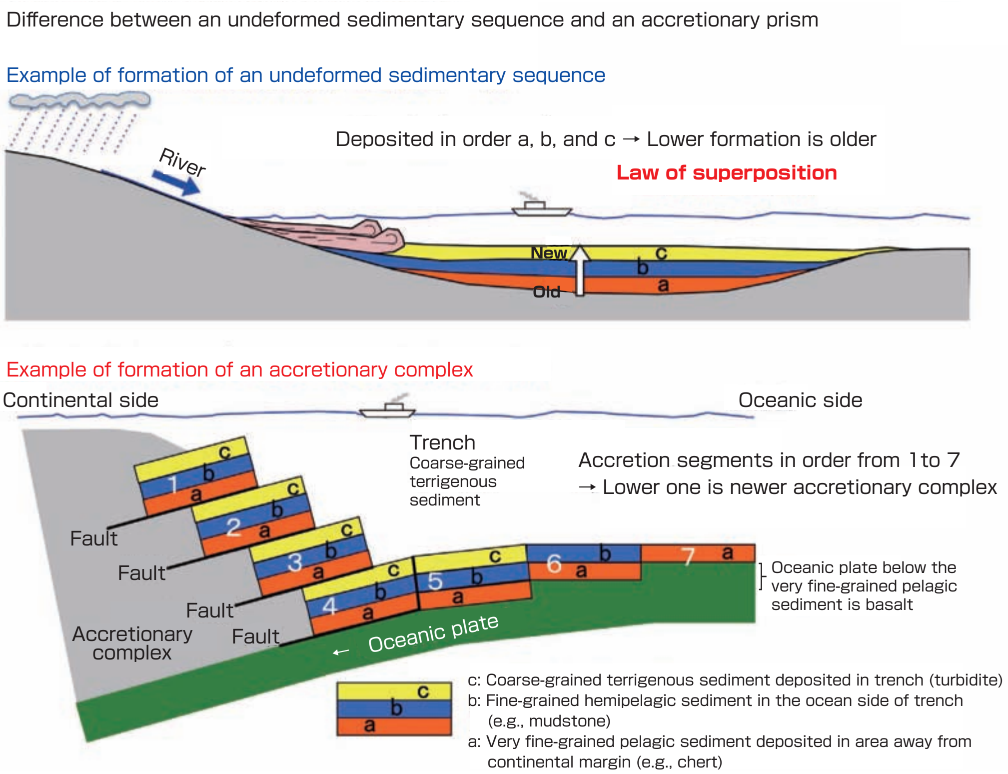

Fig. 4 Difference between an undeformed sedimentary sequence and an accretionary complex.
In an undeformed sedimentary sequence, the age of layers increases with depth (c to a). In an accretionary complex, there is an a-b-c sequence separated by low-angle faults. In each sequence, the age of layers increases in order of c to a, and sequence 1 (uppermost) is the oldest a–b–c sequence, and sequences 2 to 4 are successively younger. The stratification of the accretionary complex cannot be understood if considered in terms of an undeformed sedimentary sequence.

boundaries of their individual survey areas to ensure that the data at these boundaries was seamless.

3) An important aspect of a geological map is that the geological evolution of the rocks of the area being studied (the history of deposition and subsequent deformation of the rocks) is consistent with the present-day distribution and relationships of the rocks in the survey area. The original state of each of the rock unit identified in the survey can be determined (theoretically) by sequentially removing progressively older rock units and the effects of the deformations they have undergone. The principle of uniformitarianism states that the present-day geological processes are the same as those of the past. That is, "the present is the key to the past". Thus, the structure and relationships of the rock units as they are today must not contradict the relationships of those rock units at their time of formation. The final Tomochi geological map produced from our research was the result of many discussions among four researchers, each of whom had different areas of expertise. In comparison, a geological map created by a single university researcher often reflects the specialized interests and expertise of that researcher. Without the opportunity for discussion among researchers in other fields, it is difficult to create a highly accurate geological map.

In addition to the three points discussed above, the GSJ (the main publisher of geological maps in Japan) must ensure the accuracy of the GMJ, and its reproducibility. That is, the geological maps produced by GSJ in a particular area must not contradict maps of the area produced by others. To ensure the accuracy of their geological maps, GSJ uses an internal multistep peer-review system. GSJ mapping is also subject

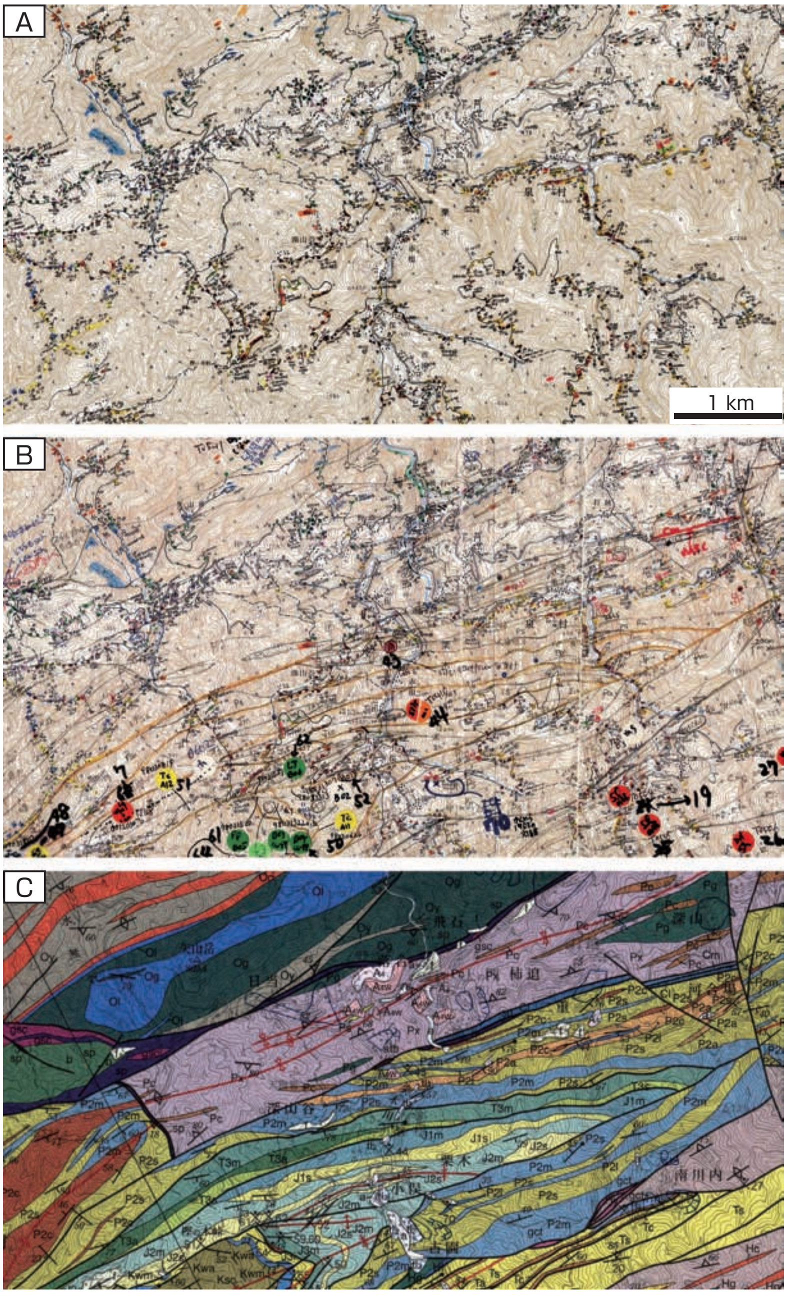

Fig. 5 From traverse map to geological map. Example of southwest area of the GMJ Tomochi 1:50,000 sheet[12].
A: Traverse map
B: Working version of the map with fossil data, formation boundaries, and faults annotated on the traverse map. Microfossil localities are shown as colored circles.
C: Part of the final GMJ Tomochi 1:50,000 sheet[12].
Base map for A and B is the Topographical Map Kakizako 1:25,000 sheet, published by the Geographical Survey Institute of Japan.

to external evaluation by the Geological Society of Japan and others. To allow confirmation of reproducibility, raw data (such as traverse maps and borehole data) are published by GSJ as research reports, and the fossils and rock samples used are registered and stored at the AIST Geological Museum so they can later be validated by other researchers. Future development of a database to catalogue these raw data would facilitate this validation.

5 Research elements in compilation of the GMJ Tomochi sheet

Integration of the research elements used in the creation of a GMJ 1:50,000 sheet is generally preceded by the following sequence of steps.

1) Before the field survey, researchers conduct a literature search and use existing aerial photos and satellite images to identify surface geological and geomorphological features, such as active faults and terraces. Before our mapping of the Tomochi sheet started in 1995, we obtained and interpreted aerial photos published by the Geographical Survey Institute and satellite images recorded by the Japanese Earth Resource Satellite 1 (JERS-1).

2) The field survey provides the basic data required for compilation of a geological map. To complete a field survey, geologists traverse the sheet area (usually on foot) looking for exposed rocks (outcrops) and record detailed observations of them. This field survey technique is most needed for the surveyor, but the know-hows are not available since it is difficult to describe them with words. The field survey approach used is of fundamental importance to the process, and varies greatly depending on the amount and type of exposed rock and the complexity of the geological structure. If the survey is in mountainous or hilly areas, the data is collected largely from outcrops near existing roads and paths, on ridges or valley floors (Fig. 5A). If the survey area is in flat country where there are few outcrops, borehole data acquired by government organizations becomes an important source of information.

The first step of the geological field survey is to determine from the available outcrops the types of strata and rocks in the area. The relationships among these are then investigated. Understanding these relationships is a particularly important part of the process. The characteristics of individual rock units can be obtained from only small areas of outcrops, but it is essential to find the boundaries between rock units to determine the relationships among them. This is achieved by developing a geological model that takes into account the scientific literature, and landforms observed from aerial photos and satellite images. The geological model indicates where there may be geological boundaries, allowing the survey to focus on those areas and thus be conducted efficiently. Because a geological survey is an observation of nature, the observations often do not exactly match the model. Therefore, as new outcrop information is gathered, the geological model is revised in the mind of the researcher to fit the new data, and the survey continues with, if necessary, a shift in emphasis influenced by the changing model.

Most of the Tomochi sheet area is mountainous, so the survey was conducted along roads, valley floors, and mountain ridges (see the traverse map of Fig. 5A). Although we expected the geology to be complex and the field survey to be time consuming, it was even more complex than we anticipated and required more time than was scheduled.

3) In addition to field observations, rock samples and fossils are collected during field work. The subsequent analyses and interpretations of these are reflected in the final geological map. The rock samples are cut into thin sections (0.02−0.03 mm thick) for microscopic examination to identify the rocks from their constituent minerals and to extract evidence of deformation and metamorphism. Samples expected to contain microfossils are chemically treated to extract the microfossils which are then examined under the microscope. Other laboratory work includes separation and identification of heavy minerals and dating of the rocks by radio-isotope methods. Together, these data can reveal properties of the rocks such as their age and the environment in which they were formed, which cannot be obtained by field observations alone. The results are fed back to the actual field survey. These contributions to the production of a geological map correspond to the academic research (*Type 1 Basic Research*) conducted by universities, and if significant results are obtained, they are published as individual papers.

The following subjects with relevance to the Tomochi sheet area were addressed by academic papers published before the creation of the GMJ.

(1) Clarification of the stratigraphy and structure of the Lower Cretaceous Tomochi Formation[13]
(2) Identification of the basement of the Lower Cretaceous Tomochi Formation as the Permian accretionary complex[14]
(3) Identification of Devonian strata from the discovery of *Leptophloeum*, a Late Devonian fern[15]
(4) Clarification of low-pressure high-temperature metamorphism of the Higo Metamorphic Complex in the northern part of the Tomochi sheet[16]
(5) Discovery and description of megacrystalline clinopyroxenite[17]
(6) Discovery of jadeite and its relationship with surrounding rocks[18]

Oral presentations to earth science and academic societies were also made on these and other related topics.

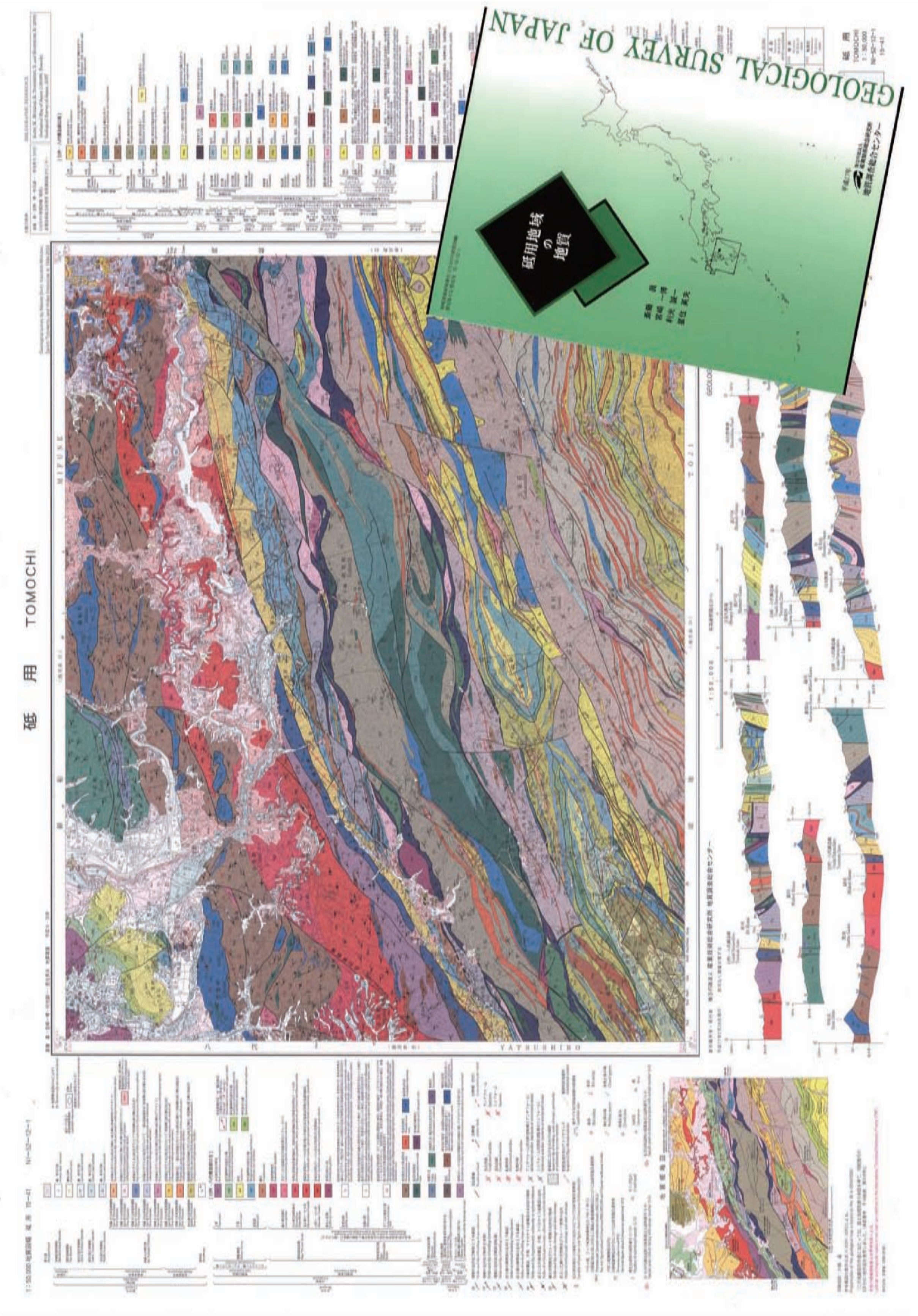

Fig. 6 Published GMJ Tomochi 1:50,000 sheet and accompanying report.
(A4 size, more than 200 pages[12])

6 Creation of the GMJ by integration of research elements

The GMJ Tomochi 1:50,000 sheet (Fig. 6) was finally compiled from the individual research elements described above. We found that the rocks exposed on the Tomochi sheet area ranged in age from the late Cambrian Period (at the beginning of the Paleozoic Era about 500 million years ago) to the present day. Classifying all of the geological features shown on the final map required 149 entries in the map legend. This is the largest number of legend entries to date for a published GMJ 1:50,000 sheet. Our map incorporated the concept of an accretionary complex and took into account the latest available information from the research papers listed in the previous section, as well as other research in the district (e.g., reports of large fossils in the area). The integration of all these sources of information produced a very detailed geological map. A report containing the data and analyses that support the final map was also published (Fig. 6). This report includes the route maps that provided the basis of the classification of the rocks and strata and the microfossil data used to determine the age of the rocks of the accretionary complex. The research that led to the final Tomochi 1:50,000 sheet provided the basic information and analysis that were used to create the regional GMJ Yatsushiro and a part of Nomo Zaki 1:200,000 sheet [19].

As previously mentioned, in creating a geological map it is important that the evolutionary model of the area is consistent with the distribution and relationships of the present-day rock units. The four researchers involved in mapping the Tomochi sheet engaged in long discussions to ensure this was the case. For example, we discussed the relationships of the Jurassic accretionary complex with serpentinite and other metamorphic rocks, with the shallow-marine deposits covered by low-angle thrust faults, and the overall geological evolution of the area.

Through these discussions we identified positive evidence that the rocks of the previously identified “Kurosegawa Belt” overlie Jurassic rocks above a low-angle thrust fault. This important finding established the existence of the Jurassic accretionary complex and is an important finding in the context of understanding the geological structure and evolution of southwestern Japan. We created a cross sectional diagram to illustrate this (Fig. 7). Moreover, through our discussions we were better able to understand the spatial and temporal relationships of the rocks of the “Kurosegawa Belt”, and also able to obtain results on the evolutionary history of the geological structure from the time it overlapped onto the Jurassic accretionary complex as a low-angle fault to present.

We also presented details of the evidence for faults in outcrops in the report that accompanies the published Tomochi sheet. This information can be used to verify our interpretation of the position, extent, and continuity of the faults. During our discussions of the faults, we were able to confirm the position of the concealed fault (i.e., where it is buried by younger sediments) and identify the faults that we could not confirm as active faults but which could be geologically recognized as active faults.

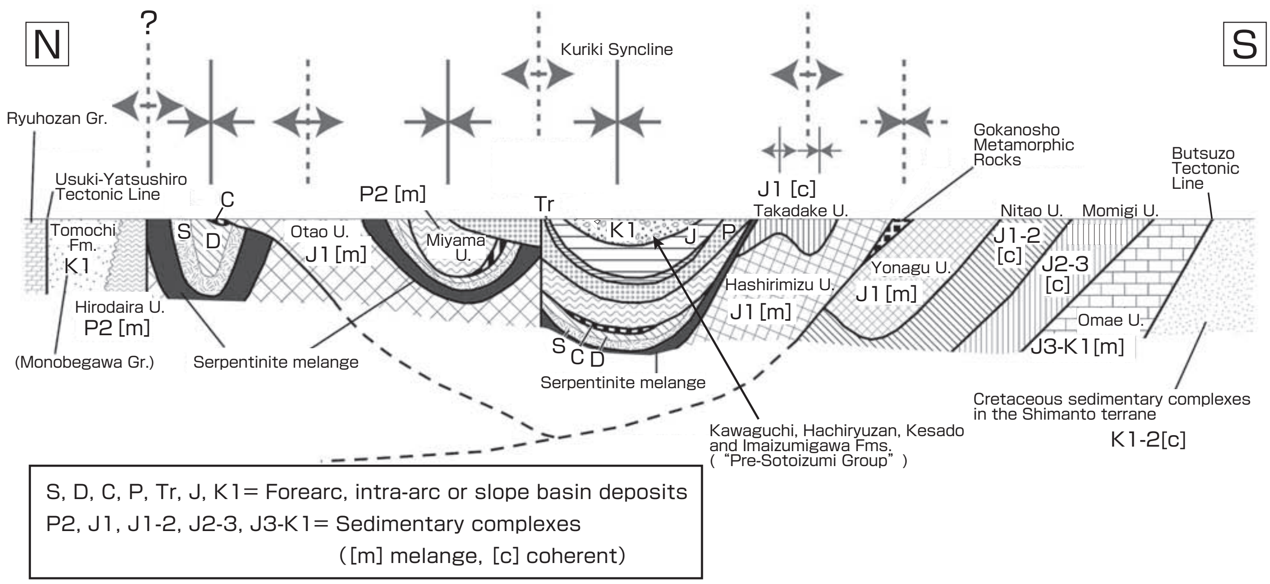

Fig. 7 Schematic cross section for the south to central area of the GMJ Tomochi 1:50,000 sheet area.
Serpentinite (serpentinite melange in the diagram), normal sediments, and the Permian accretionary complex (P2) overlie the Jurassic accretionary complexes (J1, J1-2, J2-3, J3-K1). The boundary between the Jurassic accretionary complexes and overlying rocks and strata was originally an almost horizontal fault, but was subsequently folded. This diagram summarizes the geological theory and evolution of the Tomochi district.

7 Value and uses of the GMJ Tomochi 1:50,000 sheet

The published GMJ Tomochi 1:50,000 sheet provides geological research results for an area that is geographically difficult to survey and geologically complex. We created an accurate geological map based on up-to-date geological theory and other current published information. This map will set the standard for determining the geology of this area and the surrounding region. On the basis of our work on the Tomochi sheet, we are now creating a regional-scale GMJ 1:200,000 map covering the Yatsushiro and a part of the Nomo Zaki sheet[19]. Our evidence-based interpretation of the geological structure and evolution of southwestern Japan advances the broader understanding of Japanese geology.

The published Tomochi sheet is not simply the result of basic research on individual rock units. It represents the synthesis of information from several geoscientific disciplines to create a geological map. Further, it is one individual published map of many that constitute the entire GMJ, for which there are many important uses in Japanese society.

The Tomochi 1:50,000 sheet, and the GMJ as a whole, are used not only immediately after publication. They will be valid for several decades and will continue to be used to satisfy basic societal information needs. Thus, the GMJ provides research results with a longer lifespan than, for instance, engineering research. However, some uses are expected at this point as follows.

7.1 The Tomochi sheet as a mapping standard

An example of the use of the Tomochi sheet as a standard is provided by the 1:200,000 GMJ of the Yatsushiro and part of the Nomo Zaki sheets[19]. In compilation of this map, the rock classifications of the Tomochi[12] and the GMJ Shiibamura 1:50,000 sheets[20] were used. Within this 1:200,000 sheet area, the geological classification of the Tomochi sheet was the most complex, and its completion was a prerequisite for compilation of the entire 1:200,000 sheet, which filled the last blank area of the GMJ 1:200,000 series in Kyushu.

7.2 Industrial locations

The Tomochi sheet clarified the relationship of the Jurassic accretionary complex with the rocks of the “Kurosegawa Belt” (that the “Kurosegawa Belt” rocks overlie the Jurassic accretionary complex above a low-angle thrust fault) (Fig. 7).This understanding can be transferred to improve understanding of industrial locations in areas of similar geology (e.g., the location of the Sendai Nuclear Power Station in Kagoshima Prefecture).

7.3 Disaster prevention

We believe the Tomochi sheet can contribute to the prediction of landslides, because it has clarified the structural relationships in areas of serpentinite rocks, where landslides are known to occur. Further, there are frequent failures of road embankments in the Tomochi area, for roads ranging from National highways to forest roads. These failures are commonly related to the local geology. Thus, the Tomochi map can provide basic information that can be used to develop measures to prevent these failures.

In the report that accompanies the Tomochi sheet, we have described both faults that have been repeatedly active since the late Pleistocene (125,000 years ago), and which are expected to cause future earthquakes, and faults that were not identified as active because there were no formations younger than the late Pleistocene to provide evidence of their activity. The map and report can therefore be used for investigation of regional crustal movement during the period from the late Pleistocene to the present.

7.4 Mining resources

Mapping of the Tomochi sheet indicated that the prospects for metal resources in the area are poor. It showed that limestone rocks are abundant in the mountainous regions, but that further development of these resources is unlikely, except in the northern area where there is current mining and transport infrastructure available. The prospects for other mineral resources and crushed stone are also poor. On the other hand, a hot spring developer indicated that the Tomochi sheet will be used extensively for hot spring development projects in the area.

7.5 Tourism

New uses of the Tomochi sheet include regional promotional activities and tourism. The research report that accompanies the map describes previously known sites of general interest, such as stalactite caves, and a natural stone bridge formed by welded pyroclastic rocks deposited about 90,000 years ago. There are natural features within the Tomochi sheet area that are potential national monuments, and others suitable for geo-sites or geoparks. These include previously known Cretaceous ammonite fossils, recently discovered Devonian fern fossils[15], megacrystalline clinopyroxenite[17], and deposits of jadeite[18]. These are described in the accompanying report.

Also, the geology of the mountains used for the mountain events of the National Athletic Meet as well as the mountains that comprise the unique landscape of the region are clarified, and this can be used as material to explain the natural environment of the district.

7.6 Utility value of the GMJ

The GMJ Tomochi 1:50,000 sheet will have many uses for decades after its publication. In addition to conventional uses of geological maps, new uses may arise in response to changes in society, or to the occurrence of natural disasters.

For society to continue sustainable development, human beings must have a scientifically based understanding of the natural environment. The GMJ Tomochi sheet and the GMJ in general are expected to play a crucial role in providing this understanding.

References

[1] Geological Survey of Japan: 1:1,000,000 Geological Map of Japan (3rd ed.), *Geological Survey of Japan* (1992).
[2] Y. Isozaki and T. Itaya: Pre-Jurassic klippe in northern Chichibu Belt in west-central Shikoku, southwestern Japan; Kurosegawa Terrane as a tectonic outlier of the pre-Jurassic rocks of the inner zone, *J. Geol. Soc. Japan*, 97, 431-450 (1991) (in Japanese with English abstract).
[3] Y. Isozaki, T. Hashiguchi and T. Itaya: The Kurosegawa Klippe; an examination, *J. Geol. Soc. Japan*, 98, 917-941 (1992) (in Japanese with English abstract).
[4] Technology Information Department (TID), National Institute of Advanced Industrial Science and Technology (AIST): Case studies on outcome produced by National Institute of Advanced Industrial Science and Technology (2) − Life cycle assessment (LCA) of Geological Map of Japan and Silicon semiconductor, *TID Report, AIST-TID-R2004-01*, (2004) (in Japanese).
[5] R. L. Bernknopf, D. S. Brookshire, D. R. Soller, M. J. McKee, J. F. Sutter, J. C. Matti and R. H. Campbell: Societal value of geologic maps, *USGS Circular 1111* (1993).
[6] M. Ogasawara and K. Ooi (eds.): Societal value of geologic maps − Japanese translation of USGS Circular 1111 and reviews of studies on the economic evaluation of geologic maps in the United States, *GSJ Interim Report*, 37, (2006) (in Japanese with English abstract).
[7] Technology Information Department (TID), National Institute of Advanced Industrial Science and Technology (AIST): Sansoken ni okeru autokamu jireichosa [7] Chishitsuzufuku (Case studies on outcome produced by National Institute of Advanced Industrial Science and Technology, 7. Geological Map of Japan), *AIST TODAY*, 5(5), 40-41 (2005) (in Japanese).
[8] M. Saito: The change of geologic maps in the Yokoyama district, *Chishitsu News*, 561, 4-4 (2001) (in Japanese).
[9] M. Miyamura: Stratigraphy and geological structure of the Permian formations of Mt. Ibuki and its vicinity, central Japan, *Geol. Surv. Japan Report,* 224 (1967).
[10] Gifu Prefecture: *Tochibunrui kihon chosa "Yokoyama" (Scale 1:50,000 Fundamental Land Classification Survey "Yokoyama")*, Gifu Prefecture (1995) (in Japanese).
[11] M. Saito and Y. Sawada: Geology of Yokoyama district, with Geological Sheet Map at 1:50,000. *Geological Survey of Japan* (2000) (in Japanese with English abstract).
[12] M. Saito, K. Miyazaki, S. Toshimitsu and H. Hoshizumi: Geology of Tomochi district, with Geological Sheet Map at 1:50,000. *Geological Survey of Japan*, AIST (2005) (in Japanese with English abstract).
[13] T. Kawano, H. Tanaka, T. Takahashi, S. Toshimitsu and D. Mori: Stratigraphy and structure of the Lower Cretaceous Tomochi Formation in the Chichibu terrane, Kumamoto Prefecture, *Bull. Goshonoura Cret. Mus.*, 3, 11-22 (2002) (in Japanese with English abstract).
[14] M. Saito and S. Toshimitsu: Permian radiolarian fossils from the basement of the Lower Cretaceous Tomochi Formation in the Tomochi area, central Kyushu, *J. Geol. Soc. Japan*, 109, 71-74 (2003)(in Japanese with English abstract).
[15] M. Saito, K. Saiki and S. Toshimitsu: Late Devonian *Leptophloeum* from the coherent strata in the Kurosegawa Belt, Tomochi district, central Kyushu, *J. Geol. Soc. Japan*, 109, 293-298 (2003) (in Japanese with English abstract).
[16] K. Miyazaki: Low-P-high-T metamorphism and the role of heat transport by melt migration in the Higo Metamorphic Complex, Kyushu, Japan, *J. Metamorphic Geol.*, 22, 793-809 (2004).
[17] M. Saito, K. Miyazaki and H. Tsukamoto: Clinopyroxenite in serpentinite melange of the "Kurosegawa Belt" in the Izumi-Tomochi area, Kumamoto Prefecture, central Kyushu, *Bull. Geol. Surv. Japan*, 55, 171-179 (2004) (in Japanese with English abstract).
[18] M. Saito and K. Miyazaki: Jadeite-bearing metagabbro in serpentinite melange of the Kurosegawa Belt in Izumi Town, Yatsushiro City, Kumamoto Prefecture, central Kyushu, *Bull. Geol. Surv. Japan*, 57, 169-176 (2006) (in Japanese with English abstract).
[19] M. Saito, S. Takarada, S. Toshimitsu, K. Mizuno, K. Miyazaki, H. Hoshizumi, S. Hamasaki, K. Sakagushi, T. Ono and Y. Murata: Geological Map of Japan 1:200,000, Yatsushiro and a part of Nomo Zaki, *Geological Survey of Japan,* AIST (2010) (in Japanese with English abstract) (in press).
[20] M. Saito, K. Kimura, K. Naito and A. Sakai: Geology of Shiibamura district, with Geological Sheet Map at 1:50,000, *Geological Survey of Japan* (1996) (in Japanese with English abstract).

Author

Makoto Saito

Completed a masters degree in earth science at Nagoya University in 1989. Employed at the Geological Survey of Japan in 1990. Joined the Institute of Geoscience, AIST, as Senior Researcher in 2001, leader of Seamless Geoinformation Research Group, Institute of Geology and Geoinformation since 2009. Works mainly on the geology of accretionary complexes from Kyushu to the northern Ryukyu Islands. Primary author for four 1:50,000 sheets and four 1:200,000 sheets of the GMJ and co-author for two 1:200,000 sheets. Also active in dissemination of geological information.

Discussions with Reviewer

1 Use of geological data collected by other institutions

Question and comment (Akira Ono, AIST)

This article allows readers from other fields to understand that the GMJ 1:50,000 is created, and reviewed from various viewpoints based on the latest geological findings and with consideration of how it will be used by society. It is also an excellent paper of *Type 2 Basic Research* in its structure and content.

I got the impression that the creation of a geological map, as described in this paper, is an ambitious work that predicts the three-dimensional structure of a vast subsurface space from geological data obtained from sparse outcrops on the surface. Perhaps there is not much borehole data in the region mapped, but how would available borehole data be used? Would they be used as basic data for creating the geological map, or would they be used to validate the accuracy of the created geological map? Also, local governments and private companies in that area may conduct geological surveys for their own purposes. Does AIST use such data to make its own geological maps?

Answer (Makoto Saito)

1) The reviewer is under the impression that we make our predictions from the sparse outcrops on the surface, but it is possible to obtain sufficient data even if outcrop areas are small, particularly if we walk along a traverse that allows us to observe the overall picture of the strata and rocks. When creating the GMJ, in some places the geological map can be created from traverses at wide intervals, whereas in other places it cannot be made without a very detailed grid of traverses. We devise ways to undertake our surveys so we can collect sufficient data for mapping while also keeping the cost of the survey in mind.

2) As written in the paper, if there is local government borehole data that can be disclosed, of course, we use it in the compilation of the geological map. There are not many outcrops on the plains, but there is a lot of borehole data available from local governments in these areas, and we collect and analyze them carefully to create the GMJ. This is because the underground geology is particularly important on a plain. For the Tomochi sheet, we were allowed to view some commercial borehole data (not usually disclosed) obtained by hot spring explorers.

3) We also collect and use other geological maps. These include geological maps made for the public works of local governments and the national government. If these geological maps are based on data interpretation, we consider whether the interpretations are valid from the traverse maps and reports from which the interpretations were made. We also collect sketches from dam sites and tunnel walls. For our mapping of the Tomochi sheet, we looked at the geological maps from hot spring survey reports compiled by local governments, and used them to validate our geological map (in reality, the only useful things were the traverse maps in a few small areas).

2 Expansion of coverage and update cycle of the GMJ 1:50,000

Question (Akira Ono)

I understand that the GMJ 1:50,000 series is based on the latest geological findings. What is the cycle for re-survey and revision of the GMJ 1:50,000 series? Specifically, when was the last map before the current Tomochi sheet created? I imagine a survey requires a lot of labor and time. At this point, does the GMJ 1:50,000 entirely cover Japan? Please tell us about the basic thinking concerning the expansion of the area mapped.

Answer (Makoto Saito)

1) Re-surveying for the GMJ 1:50,000 series is not planned at present because we have not yet covered all of Japan. However, we finished the first phase of the GMJ 1:200,000 in FY 2009 and some of these sheets will be replaced with new ones that incorporate the latest findings. For revision of the GMJ 1:200,000 series, the GMJ 1:50,000 sheets provide the standard for geological classification. They also provide new geological information in areas that were previously poorly understood during 1:200,000 sheet compilation. Therefore, although, in principle, priority is given to areas not yet mapped at 1:50,000 scale, a few areas essential for revision of the GMJ 1:200,000 series are also given priority.

2) The GMJ Tomochi 1:50,000 sheet had not previously been created. Surface geology maps of doubtful accuracy were produced during a Fundamental Land Classification Survey undertaken originally by the Economic Planning Agency, later by the National Land Agency, and now by the prefectures under the current Ministry of Land, Infrastructure, Transport and Tourism.

3) It will be difficult to expand the GMJ 1:50,000 series to cover all of Japan with the current number of researchers at AIST. Future expansion will be primarily into important areas such as (1) densely populated cities and surrounds, (2) areas important in terms of disaster prevention, including those subject to earthquakes and volcanic eruptions, (3) areas with high social importance such as geoparks, and (4) areas that are essential for the understanding of Japanese geology (for example, areas required for revision of the GMJ 1:200,000 series).

3 Is creation of the GMJ *Type 2 Basic Research*?

Question and comment (Akira Ono)

There is a geological research paper entitled “Creation of seamless geological map of Japan at the scale of 1:200,000 and its distribution on the web” in *Synthesiology* Vol. 1, No. 2. Referring to the “Discussion with Reviewers” at the end of the paper, “5. Researches on geological maps” contains a discussion of whether the creation of the GMJ should be considered *Type 2 Basic Research* or *Type 1 Basic Research*. What does the author of this paper think about this?

Even if the geological data of the original outcrop may be the same, the geological maps may be created quite differently, depending on the knowledge and understanding of individual geologists. If the content of the geological map depends greatly on these attributes of individual researchers, this may have a negative influence on the reliability of the map. Reliability may be improved by introducing some standard procedures for geological map creation, including a reviewing process by third parties. What is the current status for this? Please tell us if the author has any insight on this matter.

Answer (Makoto Saito)

1) In *Synthesiology* Vol. 1, No. 2, the authors state in their “Introduction” that the GMJ represents *Type 1 Basic Research* and production of a seamless geological map represents *Type 2 Basic Research*. They also suggest that the valley of death represents a “situation when the data become hard to use because they are drawn based on an old geological model.” In the final paragraph of the “Introduction,” they state that although the compilation of geological maps has aspects of *Type 2 Basic Research*, it tends to represent basic research that incorporates advanced research results and, therefore, aspects of *Type 1 Basic Research* are more prominent. On the other hand, in “Discussion with Reviewers,” a reviewer states that “there is inconsistency in the logical development to say all geological surveys up to now are *Type 1*” and “it has elements of both *Type 1* and *Type 2* … and it is grounded in *Type 2*.” However, the lead author denies that it is grounded in *Type 2 Basic Research*. To support his argument, he states that the essence of “*Type 2 Basic Research*” is to extract a generalized methodology to realize a social value, and this was not carried out in the production of their geological map.

I think the different perspectives of the head author and the reviewer depend on their different research careers. The lead author was involved in the creation of the GMJ and the reviewer was a user of geological maps. I do not agree with the reviewer’s view that GMJ is grounded in *Type 2 Basic Research*, but, unlike the lead author, I do not think it is essential that a geological map extracts a generalized methodology to realize a social value for it to be considered *Type 2 Basic Research*. I think the important element of *Type 2 Basic Research* is that the knowledge is presented in a form that can be directly used by society.

The outcome report (Reference 7) shows that there are several ways in which the GMJ is used. These include cases where particular content of the GMJ, or the entire GMJ, is used directly by an end user, and other cases where, for example, a consultant company extracts information from the GMJ directly but then provides that information to a client. In this case, the information may be provided to the client as another special geological map created from the GMJ for a specific purpose or a seamless geological map created from the GMJ. Because the GMJ can be used either directly or indirectly through a derivative map, I cannot draw a clear line between *Type 1* and *Type 2* research, but I do say that it satisfies some of the criteria for both *Type 1* and *Type 2* research. The GMJ Tomochi 1:50,000 sheet is *Type 1 Basic Research* in the minds of we who created it, but we did draw this geological map with accurate lithofacies distributions to be useful directly.

2) The several procedures applied to guarantee the reliability of the GMJ are described in the text. One of these is a multistep GSJ internal peer review system. The GMJ is published by GSJ, AIST, and is checked more thoroughly before publication than academic research papers. These checks include an internal review by geoscience specialists, by the manager of the GMJ team, and by the GSJ publication department. In fact, some completed maps have failed to pass successfully through internal checks and have never been published. After publication, we actively seek further evaluation of GMJ products by academic societies. The Tomochi sheet was reviewed in an article of the *News of the Geological Society of Japan*. Uniform notations are used in the geological maps according to Japanese Industrial Standards regulations. Because the GMJ is a product of research, it is undeniable that its quality depends on the ability of authors. However, authorship is annotated on the published GMJ; a specialist can recognize the authors and know their areas of specialization and their research skills. The display of authors' names is the driving force that an author keeps and improves accuracy.

I think the measures described above provide an appropriate guarantee of the validity of interpretation of the data and the accuracy of the published GMJ products.