Geological investigations of Sulawesi (Celebes) before 1930

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I. INTRODUCTION AND SUMMARY

This paper is an overview of the early discoveries of the geology of Sulawesi, from the first naturalist expeditions in the 1820s until the 1930s. Most of the contributions to the knowleddge of the geology of Sulawesi during the Dutch colonial era came between the late 1880s and 1930, after which geological and mining investigations essentially stopped for four-decades. Before Indonesian Independence in the 1940s, Sulawesi Island had been called Celebes, a name introduced by Portuguese explorers in the early 1500s.

Geographically, Sulawesi is rather unique among the larger islands of Indonesia. Unlike the other three large islands Sumatra, Borneo and Java, Sulawesi has four 'arms', which are all surrounded by deep seas, and virtually the entire island is mountainous terrain without major rivers or delta systems. Active volcanism is limited to the eastern half of the North Arm and the lone Una-Una volcano in the Tomini Gulf, while Miocene and recently extinct volcanoes are present in SW Sulawesi.

Geologic exploration was challenging. Surveys into uncharted territories before 1920 (before the arrival of detailed topographic maps, air photos and satellite imagery), required topographic surveying of all itineraries with chain and compass, and with a barometer for estimating altitudes.

Manuscript received: 21April 2022, revised manuscript received: 9 May 2022, final acceptance: 28 April 2022.

DOI: 10.51835/bsed.2022.48.1.391

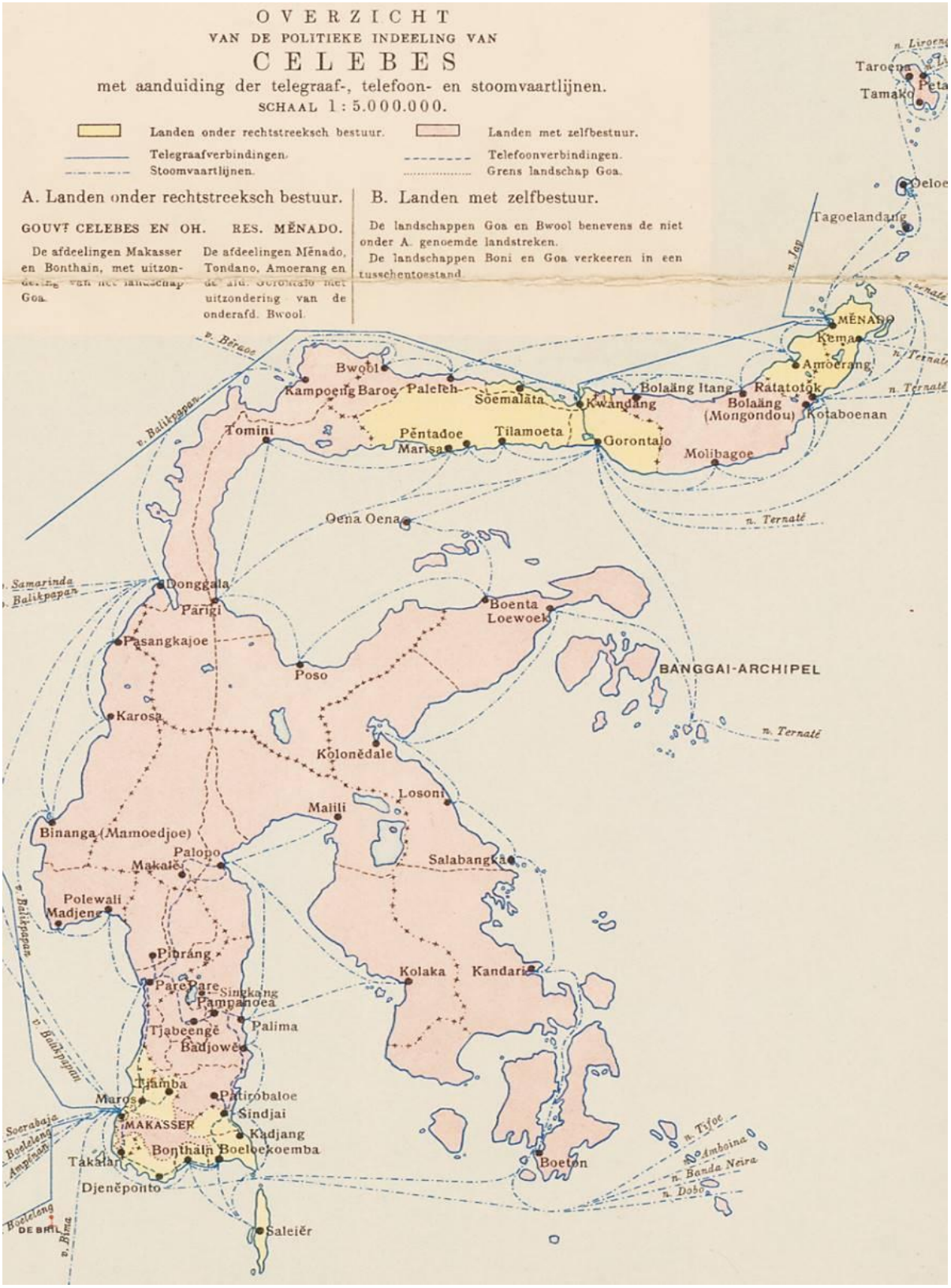


Figure 1. *Map of Sulawesi, showing the political situation in 1909. In yellow are the 'lands under direct Netherlands Indies government administration'. In pink are 'lands with self-government', i.e. areas ruled by numerous small 'rajahs' (Topographische Inrichting Batavia).*

Economic minerals of Sulawesi are limited mainly to gold and nickel, while iron was a valuable commodity among the native people. Small Eocene coal deposits are present near Maros in SW Sulawesi, but ever since the first evaluation survey by Schreuder (1854) these coal deposits were deemed to be uneconomic, until some exploitation started during the Japanese occupation.

Some of this report was taken from the book *'Pioneers and Milestones of Indonesian Geology'* (van Gorsel, 2022, 4 volumes, Institut Teknologi Bandung). For references not included at the end of this paper, see the '*Bibliography of the Geology of Indonesia and surrounding areas'* (www.vangorselslist.com)

General timeline of discovery (1880s-1930s)

Until around 1890, most of Sulawesi was a collection of partly self-governed small states, not under direct Dutch government administration. The VOC (Dutch East Indies company) had established trading posts (forts) and small settlements along the coasts of Sulawesi since the 1600s and exercised indirect influence through treaties and trading pacts with local 'rajahs'. Much of the interior of Sulawesi was inaccessible and dangerous for European travelers until around 1905-1910, by which time most of Sulawesi had been brought under some form of administration under the Netherlands Indies government.

The main reason for the initial lack of interest in Sulawesi from the VOC and the relatively late Dutch annexation was probably because Sulawesi did not produce any of the valuable spices that initially brought the Dutch to the Moluccas. Also, its mostly rugged, inaccessible terrane limited its agricultural capacity, and little or nothing was known about its mineral potential. As a result, interest in the geology of Sulawesi also remained dormant until the 1880s.

The geology of the island of Sulawesi long remained poorly known, compared to other parts of the Netherlands Indies. By 1890, initial geological mapping surveys had been carried out in large parts of Java (Junghuhn 1840s, Verbeek and Fennema 1880s), Sumatra (Verbeek 1870s), SE Kalimantan (Schwaner 1840s, Verbeek (1870s, Hooze 1880s) and West Kalimantan (Van Schelle in the mid-1880s, Wing Easton and Koperberg in late 1880s-1890s), but the geology of Sulawesi remained largely unknown until the late 1800s-early 1900s.

A significant increase of geological reconnaissance and prospecting for gold (and minor coal) in Sulawesi happened after the late 1880s until the 1920s (see also below). Probably not entirely coincidental is that after the increased interest in North Sulawesi gold, North Sulawesi was rapidly annexed and brought under direct Dutch colonial rule in the late 1880s and early 1890s. Other areas followed later: Dutch administration over Central Sulawesi was established only by 1905.

II. EARLY EXPEDITIONS (1821-1929)

II.1. Key surveys and expeditions

During the 1800s, scientific travels to Sulawesi were all conducted by government-sponsored and privately funded 'naturalists', many of whom were primarily zoologists or botanists, but some also made observations on rocks and geological features. In the late 1800s they were followed by gold prospectors, in the early 1900s by petroleum explorers and later in the early 1900s by government geologists in Geological Survey projects.

The main pioneering efforts in geology and mining in Sulawesi between the early 1800s and 1930 were:

- The first naturalist travels to Sulawesi (C. Reinwardt, H. von Rosenberg, H. Zollinger, A. Wallace; 1821-1864);
- First private gold prospecting and first prospecting support by Mijnwezen in North Sulawesi (1886- early 1900s);
- First geological reconnaissance of SW Sulawesi, by Prof. A. Wichmann (1888-1889)
- First Central Sulawesi sampling by Dutch protestant missionary A.C. Kruyt in 1895 (Wichmann, 1896);
- First systematic geological-mining reconnaissance by Mijnwezen, in North Sulawesi-Manado (1896-1906);
- Gold prospectivity evaluations for private entrepreneurs by visiting European academics H. Bucking, F. Rinne, G. Molengraaff and J. Ahlburg (1898-1909);
- Celebes expeditions by F. and P. Sarasin (1893-1896 and 1902-1903);
- Sulawesi geological reconnaissance by R. Verbeek (1899; Moluccas Expedition);
- Midden-Celebes Expeditie of E.C. Abendanon (1909-1910);
- Sulawesi East Arm surveys by petroleum geologists (1905-1929)
- Dienst van het Mijnwezen/Mijnbouw geological-mining survey projects, 1909-1930;
- Central Sulawesi expedition by H.A. Brouwer-Hetzel (1929).

By 1930 all geoscience expeditions came to a halt, probably as a direct result of the global economic crisis. Systematic geological mapping and research in Sulawesi did not restart until the 1970s, by the Indonesian Geological Survey (Sukamto, Simandjuntak, etc.)

II.2. The first Naturalists and Geologists' travels to North Sulawesi (1821-1864)

The first scientific naturalist explorer in Sulawesi was probably the German botanist Prof. Casper G.C. Reinwardt (founder of the Bogor Botanical Gardens in 1817), who traveled across parts of North Sulawesi in October 1821 and reported on some of its active volcanoes and on several small native small gold mines in Gorontalo, Sumalata, etc. (Figure 2). He was the first to describe how native miners wash gold from intensely weathered veins in the granites, volcanic breccia and porphyrite. Reinwardt was the first European to climb the Soputan volcano in North Sulawesi, in 1821 and

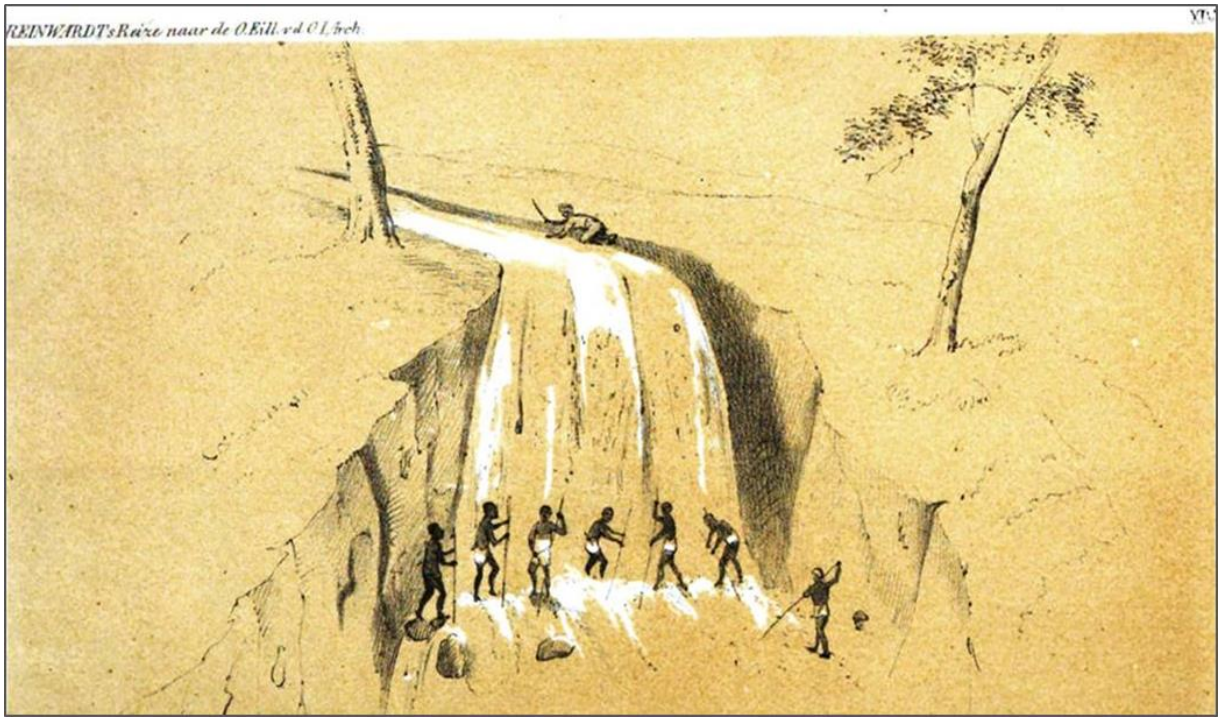


Figure 2. *Native gold diggings in Gorontalo, North Sulawesi, as observed and drawn by C. Reinwardt in 1821.*

noted the unusual obsidian volcanic rocks.

Next came E.A. Forsten, a young Dutch medical doctor with a strong interest in plants with medicinal properties. He arrived in the Netherlands Indies in 1838, as a naturalist for the Dutch Natuurkundige Commissie (Natural History Committee) in Leiden. The instructions for his multi-year mission to Celebes from late 1838 until early 1843, were to collect zoological and botanical specimens, but as-per-usual for members of the *Commissie*, he was also instructed to observe the geology and economic minerals and collect rock samples. Forsten was the only *Commissie* member to set foot in Sulawesi. He was accompanied on his travels by German surveyor/illustrator Heinrich von Gaffron, who would later conduct his own expeditions in Borneo.

Like Reinwardt, Forsten inspected a number of local gold diggings in 1840 and 1841 and collected gold samples. Unfortunately, he died of disease in Ambon in 1843, at age 31. Forsten's collections reached the Natural History Museum in Leiden, but due to his untimely death, the results of his travels were never documented or published.

In 1863, Netherlands Indies Army officer/surveyor and naturalist Hermann von Rosenberg traveled across the Gorontalo District in the North Arm of Sulawesi, sponsored by the Netherlands Indies government. One of the more interesting chapters in Von Rosenberg (1865, 1878) is on his October visit to the gold mines at

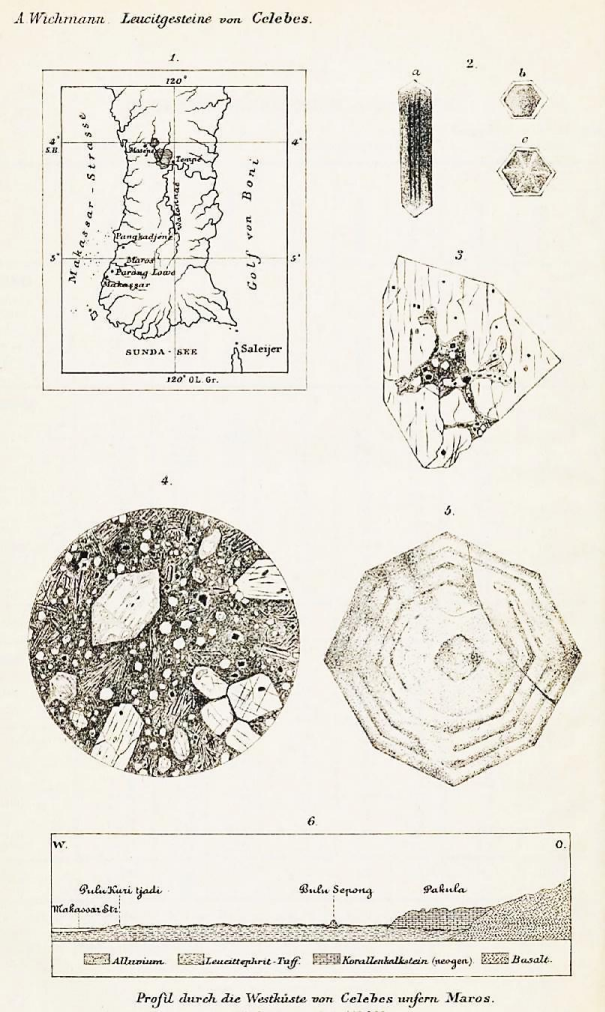


Figure 3. *Thin section of leucite basalt from SW Sulawesi (Wichmann, 1893, Leucitgesteine von Celebes).*

Soemalatta (Sumalata) from the village of Kwandang on the North coast. Gold-bearing quartz veins had been discovered here 50 years earlier by native people and had been mined from 26 pits, 15-90m deep. All but two of the shafts were abandoned at the time of Von Rosenberg's visit. Von Rosenberg (1878) made occasional references to rock types in the Gorontalo area. He also collected rock samples, but it is not clear if these were ever studied.

Two private naturalist travelers worth mentioning who spent time in SW Sulawesi included Swiss naturalist Heinrich Zollinger in 1847 and British Alfred R. Wallace in 1857. Both funded their travels by collection botanical and zoological specimens, which they sold to museums in Europe.

II.3. First SW Sulawesi geological reconnaissance by Prof. A. Wichmann (1888-1889)

Prof. Arthur Wichmann of the University of Utrecht traveled extensively through the Eastern Indonesia islands in 1888-1889, sponsored by the Netherlands Geographic Society. In 1888 he visited SW Sulawesi. In the Maros area he was the first to discover leucite basalt and tuffs in the Pajangkene and Walanae Rivers (Figure 3). He was probably also the first to describe common glaucophane-bearing metamorphic schists from SW Sulawesi, in float of the Pajangkene River (Wichmann, 1893; presumably derived from the Bantimala basement terrane).

Kruijt also sampled serpentinized ultramafic rocks NE of Poso, at Tanjung Api along Tomini Bay, the locality of an enigmatic burning gas seep (described in more detail by M. Koperberg in, 1905; see also separate paper on Tanjung Api in this journal). A.C. Kruijt also accompanied Mijnwezen geologist/mining engineer R. Fennema and J.F. de Corte in November 1897, when Fennema accidentally drowned in a boating accident on Lake Poso during a sudden rainstorm.

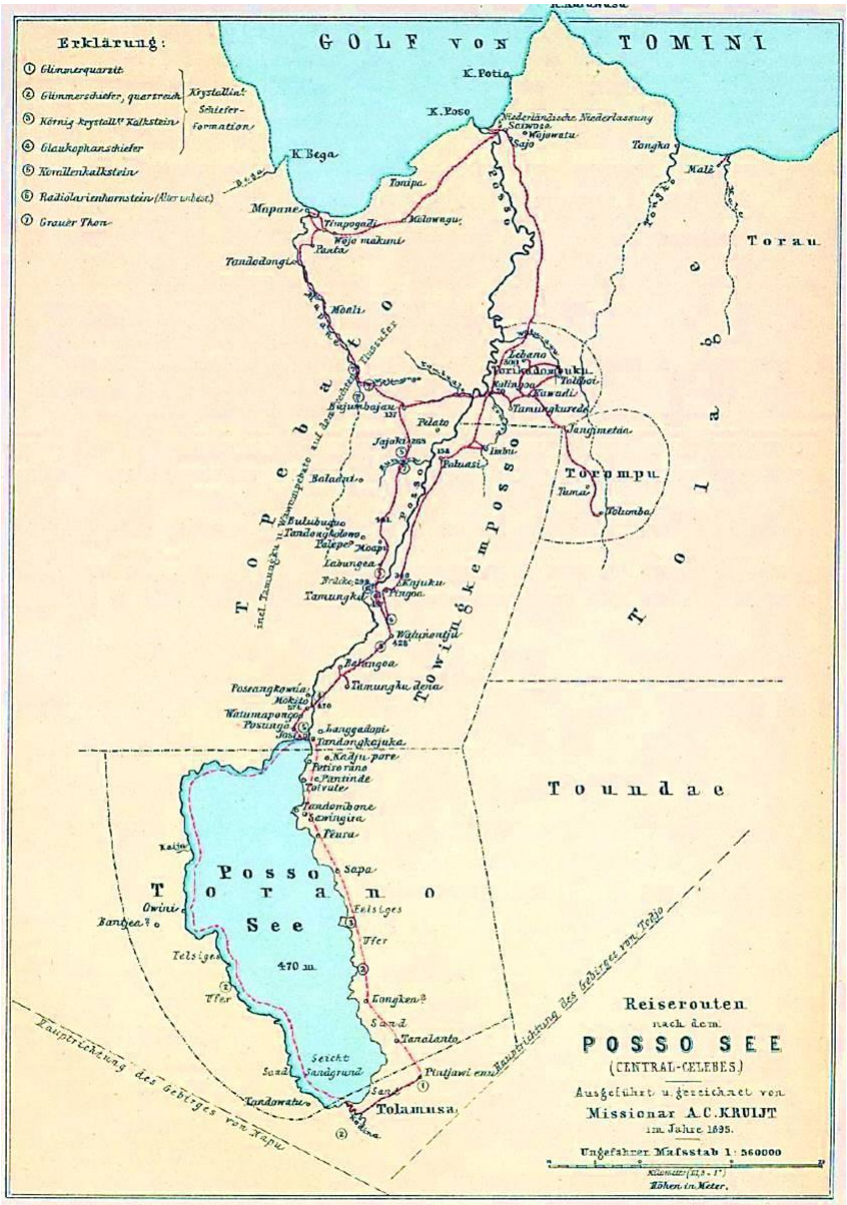


Figure 4. *Itinerary and sample localities of missionary Alb. C. Kruijt in November 1895, with the first records of crystalline schists and quartzites (1,2,3) around Lake Poso and glaucophane blueschist (4) and Mesozoic radiolarian chert (6) North of Lake Poso (in Wichmann, 1896). The Sarasin cousins had probably visited the lake just before this, but no results had been published at the time of the Wichmann paper.*

Another interesting Wichmann 'first' was from Central Sulawesi, in his 1896 description of the metamorphic rocks of the Poso Lake area, based on the samples collected by Dutch Calvinist missionary Albert C. Kruijt in 1895 (Figure 4). Kruijt (1869-1949) was the first European to settle in the Poso area in 1891 but was more interested in studying the geography and the ethnography and sociology of the Toraja peoples of Central Sulawesi than in converting them to Christianity: his first conversion to Christianity was only in 1909.

II.4. The Sarasin Celebes naturalist-geological expeditions (1893-1896 and 1902-1903)

Two well-known, major, privately funded naturalist expeditions were conducted across all parts of Sulawesi by two Swiss naturalist cousins Paul and Fritz Sarasin, the first in June 1893-March 1896, the second in March 1902-April 1903. The Sarasins

Figure 5. *Itineraries of the Sarasin cousins in North, Central, SW and SE Sulawesi in 1893-1896 and in 1902-1903 (Sarasin and Sarasin 1905).*

contributed much new knowledge about the geography of parts of Sulawesi (especially Central Sulawesi), areas which had never been visited before by European naturalists or geologists. Much of their interest was in freshwater molluscs and in zoogeography and the position of the Wallace Line (which separates the Indo-Malayan and Australian-Papuan faunal-floral provinces).

During the first expedition, the Sarasins journeyed across the Minahasa province of North Sulawesi and across Central Sulawesi. One of the more significant journeys was across Central Sulawesi, from the Gulf of Bone via Lake Poso to the Gulf of

Figure 6. Up: *Fritz and Paul Sarasin during their second Sulawesi expedition in 1902 (Coll. Tropenmuseum).* ***Right:*** *'Orographic map of Celebes' from Volume 4 of 'Materialien zur Naturgeschichte der Insel Celebes', a simplified version of mountain ranges of Sulawesi (Sarasin and Sarasin, 1901).*

Tomini early 1895. This was the first visit by geologists/naturalists to Lake Poso (only a Dutch government official and a missionary had traveled here before). During their second Celebes expedition in March 1902-April 1903, the Sarasins made additional crossings of Central and SW Sulawesi (Figure 5).

The extensive Sarasin reports mainly documented their geographic and ethnographic reconnaissance, but they also included data on the geology along the way and collected rock samples. The results of the first expedition were documented in four volumes (Sarasin & Sarasin, 1898-1901). Volume 4 documents the geographic and geological results, with brief descriptions of rocks samples by Prof. H. Bucking in Strasbourg and Prof. C. Schmidt in Basel.

The Sarasins were the first to describe several rock complexes that are now well known:

- Metamorphic rocks in Central Sulawesi, including the subduction zone indicator glaucophane schist;
- Peridotites, gabbro and serpentinites the Matano and Towuti Lakes area of eastern Central Sulawesi and in the SE Arm of Sulawesi.
- Eocene-Miocene limestones and coal in the Maros District of SW Sulawesi, etc.

The Sarasins were probably the first to describe the prominent WNW-SSE trending Palu River valley and Palu Bay in NW Sulawesi. It is now known as the Palu-Koro rift valley and is believed to represent a pull-apart basin along the Palu-Koro sinistral strike-slip fault zone (Katili, 1970). In a tribute to the Sarasins pioneering expeditions in Celebes, Abendanon (1915-1917) named it the 'Fossa Sarasina' (the graben of the Sarasin's).

II.5. The Abendanon Midden-Celebes Expeditie (1909-1910)

Dutch mining engineer E.C. Abendanon conducted an extensive series of geological traverses across Central Sulawesi in April 1909- August 1910, sponsored primarily by the Koninklijk Nederlands Aardrijkskundig Genootschap (KNAG, Royal Netherlands Geographic Society). This was first geologic-geographic expedition in Central Sulawesi since the more geographic/ethnographic- focused travels of the Swiss cousins P. and F. Sarasin in the late 1800s.

Abendanon traversed Sulawesi for 200 field days, about 2000 km on foot, 400 km on horseback and about 1000 km in canoes (Figures 7 and 8). The expedition was an impressive feat in logistics across areas that had long been inaccessible and had never been visited by European scientists before. A large amount of new information was gathered by Abendanon, but it obviously was a reconnaissance survey.

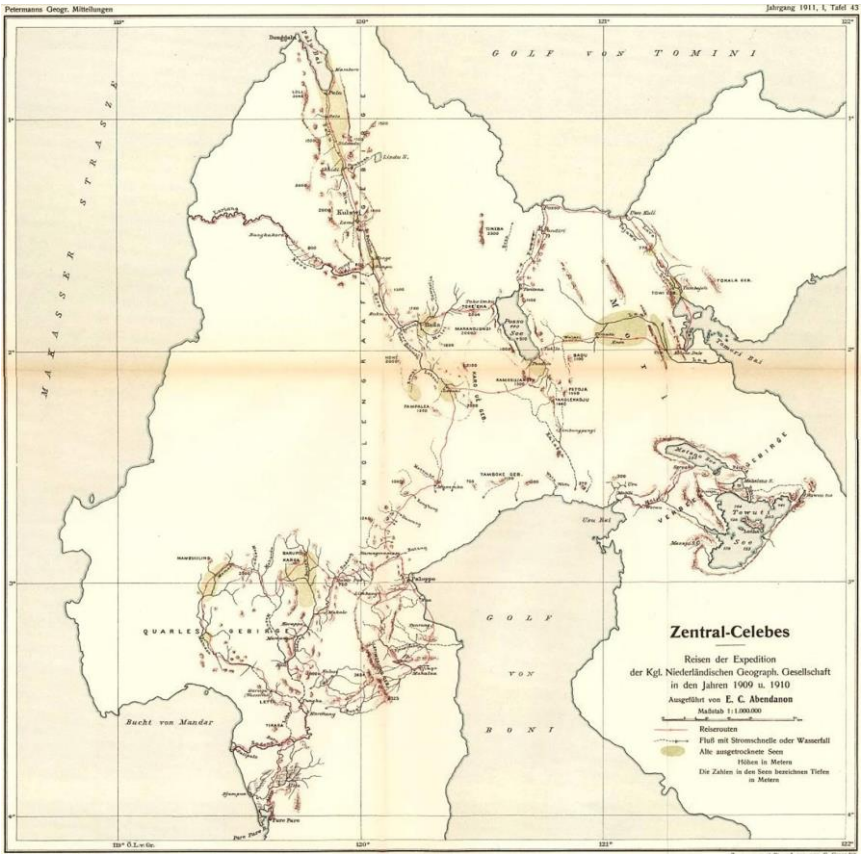


Figure 7. *Itineraries of E.C. Abendanon in Central Sulawesi in 1909-1910 (in red).*

The results of the Sulawesi Expedition of Abendanon were published in a voluminous 4-volume set of books and an Atlas volume, in both Dutch and French editions (Abendanon, 1915-1917; for more see the Abendanon chapter in Van Gorsel, 2022). The reports include chapters on petro-graphy by W.F. Gisolf, Cretaceous-Tertiary fossils by French paleonto-logist G.F. Dollfus and Mesozoic radio-

laria by British micropaleontologist G.J. Hinde.

Tectonics of Sulawesi (Abendanon, 1912, 1916)

In 1912 Abendanon published his version of the principal tectonic elements of Sulawesi, which, for the first time reasonably well characterizes its main building blocks, from East to West (Figure 9):

1. Large and thick peridotite complex of eastern Central Sulawesi, named the Verbeek Mountains by Abendanon, and was investigated by around the Matano and Towuti lakes (green on Figure 9).

2. N-S belt dominated by mica-schists and quartzite without any granites across Central Sulawesi, named the Fennema Range (light blue);

3. N-S belt of granites and gneiss-type metamorphics, named the Molengraaff Range, from the 'neck' of Sulawesi to the south (pink);

4. Not addressed on Figure 9 are the SW Sulawesi area of Neogene granites and extinct volcanoes with potassic volcanics, and the North Arm, dominated by 'normal' calk-alkaline arc volcanics.

Another interesting observation and conclusion of Abendanon was that the tops of the igneous-metamorphic mountains in the Molengraaff and Fennema mountain ranges are relatively flat and not higher than 2000m in altitude. From this he concluded that the central parts of Sulawesi had been eroded to a flat peneplain by Oligocene time and was subsequently uplifted by ~2000m in Late Tertiary time. After this uplift,

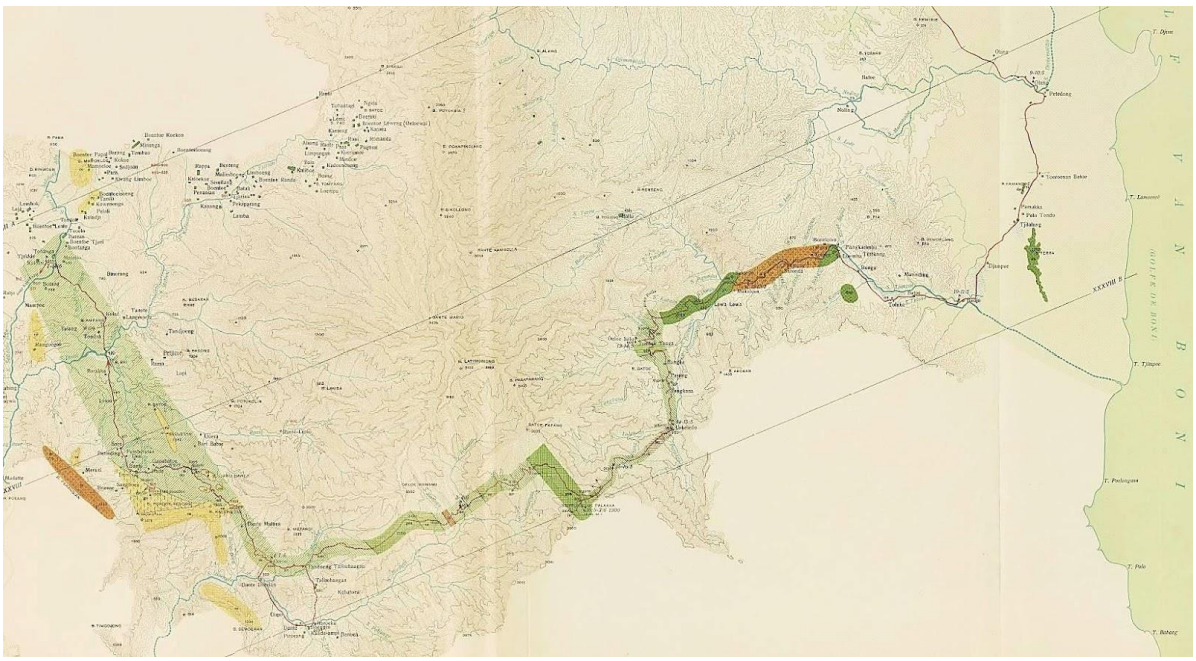


Figure 8. *Example of part of Abendanon's documentation of the geology along his 1909-1910 traverses, from the Gulf of Bone to Makassar Straits via the Latimojong basement high (Abendanon, 1915).*

significant erosion/incision followed, with deposition of the 'Celebes Molasse' along the margins (Abendanon, 1912, 1916).

In 1916 Abendanon also made important observations about the 7000 km2 large peridotite massif in the Verbeek Mountains of Eastern Sulawesi, which amounted to the first accurate description of 'Oceanic lithosphere stratigraphy' (although he did not recognize it as such). The observed stratigraphy, from bottom to top, includes:

1. A peridotite core, at least 1100m thick (= mantle);

2. This core is enveloped by a succession of gabbros, overlain by diabase (= basalt), diabase breccias and diabase tuffs (= typical oceanic crust);

3. The basaltic rocks are overlain by remnants of a thin sediment cover, composed of up to 200-300m of radiolarites and pelagic limestones of Jurassic-Cretaceous-age (typical pelagic ocean floor sediment).

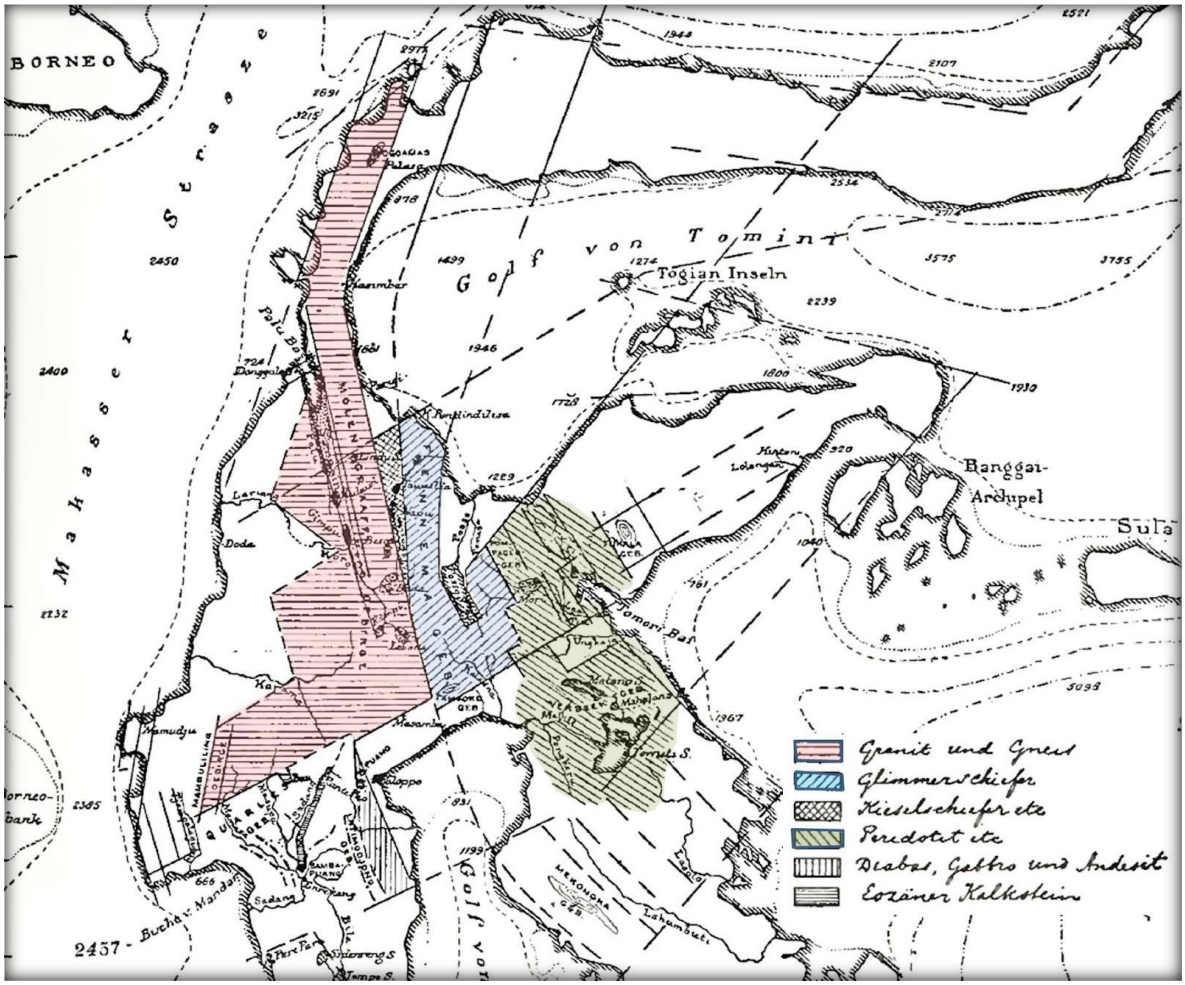


Figure 9. *A map of the main tectonic elements of Central Sulawesi by Abendanon (1912).*

From literature data, Abendanon (1916) assumed that similar successions of peridotite cores with gabbro-diabase envelopes are present in other parts of eastern Indonesia, like Halmahera-Waigeo, Obi, Ambon- East Ceram and Timor-Moa).

Finally. the pronounced NNW-SSE trending Palu River valley and Palu Bay (now known as the Palu-Koro strike-slip fault zone) was recognized as a young 'rift' and was named the Fossa Sarasina (Sarasin Trough), in honor of the Sarasin cousins.

Nickel deposits of Eastern Central Sulawesi (Abendanon 1912-1918)

One of the most significant results of the Abendanon Sulawesi expedition was the recognition of iron and nickel-chromium ores in the lateritic weathering zones of the large ultramafic rock outcrops near the Towuti and Matano lakes in eastern Central Sulawesi. Some of the iron ores had already been exploited by native populations. The Sarasin cousins had also observed ultramafic rocks in the area in 1896, but their samples were never analyzed for nickel content (Sarasin and Sarasin, 1901). In volume 4 of his main opus on the Celebes Expeditie (1917) Abendanon described the ore deposits, with chemical analyses by Prof. S.J. Vermaes of the TH Delft, confirming the presence of potentially commercial nickel content.

In his book and several later papers (e.g. Abendanon, 1918), Abendanon argued that 'the volume of nickel ore in the Verbeek Mountains will make the Netherlands Indies one of the richest nickel-producing countries in the world' (De Ingenieur 22, 2 June 1917). This opinion was disputed by various mining engineers at that time, but the nickel deposits identified by Abendanon have since been successfully mined by private and government enterprises since the 1960s, and today the Sorowako area is indeed part of the largest nickel-producing region in the world

Abendanon's discoveries led to follow-up evaluation surveys of nickel deposits by the Dienst van het Mijnwezen between 1917 and 1922 (Dieckmann, 1919, 1925; Adam, 1922) and later by the private Billiton mining company in 1940-1950 (led by G.L. Krol, a son of Mijnwezen engineer L.H. Krol). Although small-scale nickel mining was conducted here by two private companies in the late 1930s (and continued by the Japanese occupation force in 1942-1945), significant commercial nickel production started only in the 1970s (by PT INCO, PT Vale, PT Aneka Tambang).

Status of geological mapping of Indonesia (Abendanon, 1915)

After his return from the Sulawesi, Abendanon was commissioned by the Royal Netherlands Geographic Society (KNAG) and the Maatschappij tot Bevordering van het Natuurkundig Onderzoek der Nederlandsche Kolonien, to compile the first country-wide Geologische schetskaart van Nederlandsch Oost-Indie (Geological sketch map of the Netherlands Indies). The work was conducted between 1911 and 1913 and was published in 1914,

in 6 sheets at 1:2.5 million scales. Perhaps the most useful part of the Abendanon map today is to realize how much of Sulawesi was still unexplored in 1913 ('blank' areas; Figure 10).

II.6. The Brouwer-Hetzel-Straeter Sulawesi expedition (1929)

Although supported by the Geological Survey with logistics and personnel, the expedition across Central Sulawesi was essentially a private academic undertaking. H.A. Brouwer, Professor of Geology at the University of Amsterdam was in Bandung for the Fourth Pacific Science Congress in 1929. After the congress, Brouwer embarked on a 4.5-month expedition to Central Sulawesi from June until October 1929, accompanied by Mijnbouw geologists W.H. Hetzel and H.E.G. Straeter (published as Brouwer 1934). Hetzel was a former Brouwer student in Delft, who had been seconded to the MGO Oost Celebes (Mining-Geological Survey East Sulawesi) project in 1925-1929, based mainly in Bau-Bau on Buton Island.

By this time, the main patterns of the geology of Central Sulawesi had

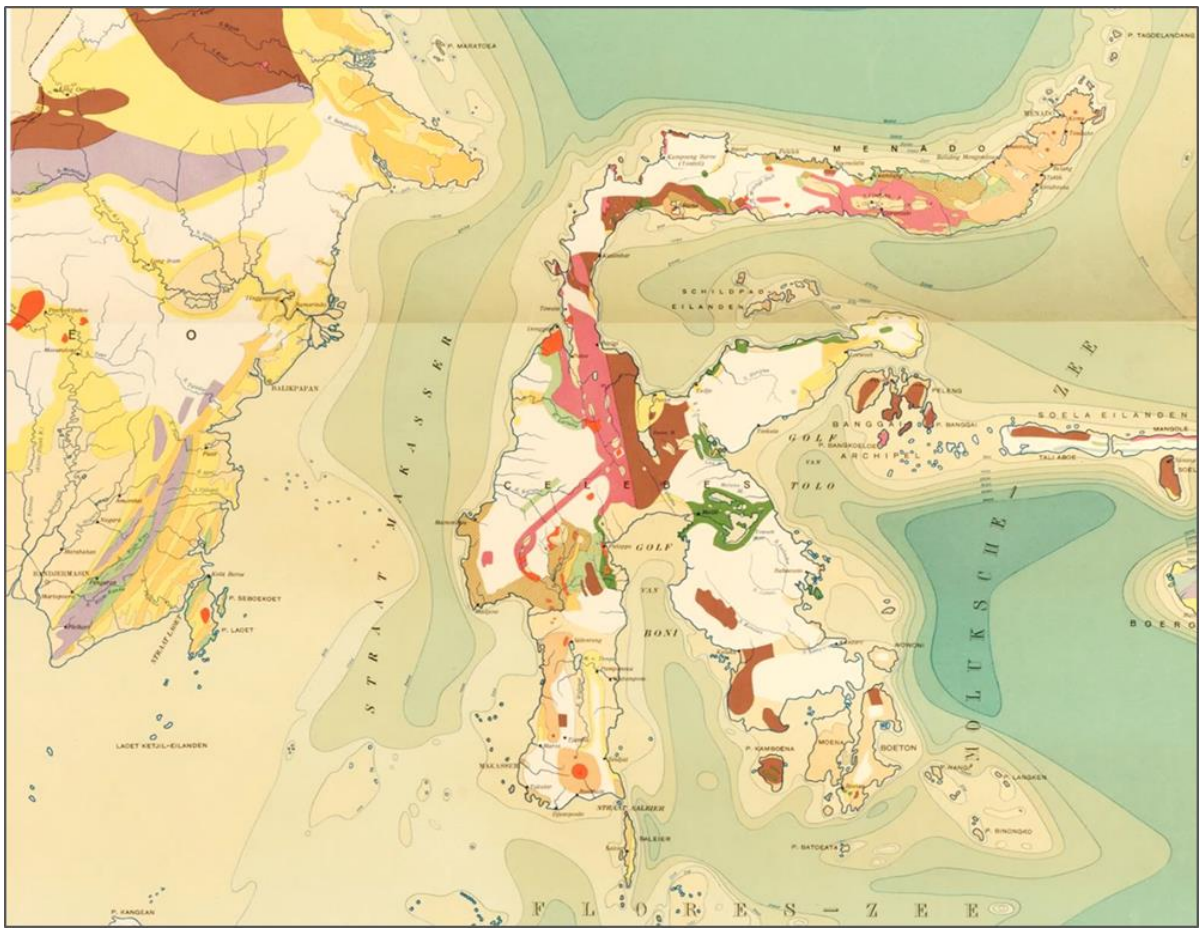
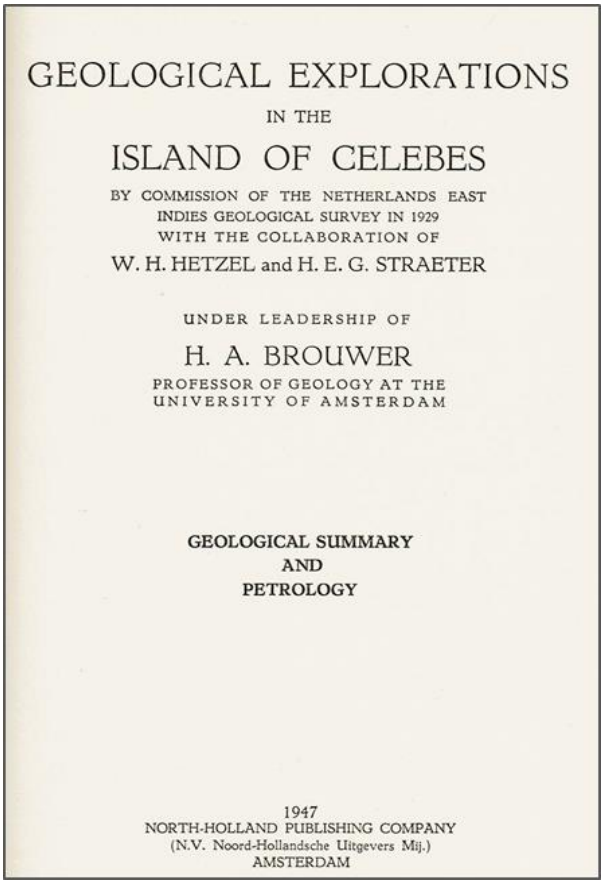


Figure 10. *Detail of the first 'Geologic overview map of the Netherlands Indies' by Abendanon (1915). After the Abendanon expedition more of the geology of Sulawesi is known than at the time of Verbeek (1908). However, half of Sulawesi is still completely unexplored (white areas), and much of the colored areas still need to be viewed as geological reconnaissance (Van Waterschoot van der Gracht, 1915c).*


GEOLOGICAL EXPLORATIONS
IN THE
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BY COMMISSION OF THE NETHERLANDS EAST INDIES GEOLOGICAL SURVEY IN 1929
WITH THE COLLABORATION OF
W. H. HETZEL and H. E. G. STRAETER
UNDER LEADERSHIP OF
H. A. BROUWER
PROFESSOR OF GEOLOGY AT THE UNIVERSITY OF AMSTERDAM
GEOLOGICAL SUMMARY AND PETROLOGY
1947
NORTH-HOLLAND PUBLISHING COMPANY
(N.V. Noord-Hollandsche Uitgevers Mij.)
AMSTERDAM

Figure 11. *Cover of the report on the results of the Brouwer Sulawesi expedition of 1929 (Brouwer, 1947).*

become clear. Brouwer (1930) distinguished three main zones: (1) an eastern zone with abundant imbricated basic-ultrabasic igneous rocks, radiolarian cherts and Mesozoic limestones; (2) a central zone dominated by crystalline schists, with deformational strike directions mainly N-S; (3) a western zone with abundant granitic rocks and with Mesozoic sediments of different facies from zone 1 (Figure 12).

Samples of metamorphic rocks collected during the Brouwer 1929 expeditions were described later at the University of Amsterdam by Willems (1937), De Roever (1947) and Egeler (1947). These were groundbreaking works in classification of metamorphic rocks into 'metamorphic facies':

1 The petrographic study of Willems (1937) on metamorphic rocks showed all rocks to be of epi- to meso-metamorphic grade, with a general increase in metamorphism from East to West;

2. The Egeler (1947) petrographic work on rocks from the northern part of western Central Sulawesi and the southern part of the Sulawesi 'neck' documented intense contact metamorphism around the young ('alpine') granodioritic intrusions of West Sulawesi, which was superimposed over older regional metamorphism;

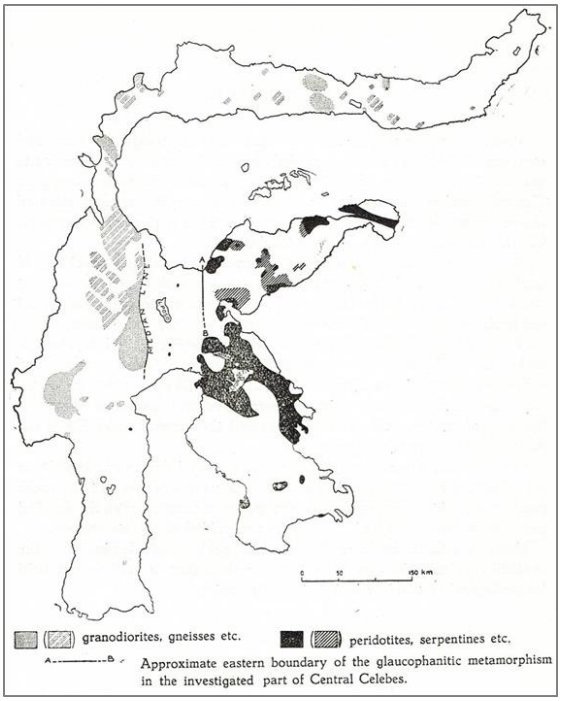

Figure 12. *Map showing the main geologic terrains of Sulawesi: mainly granites in the West, crystalline schists in the center and ultrabasic igneous rocks and Mesozoic deep marine sediments in the East (Brouwer, 1947).*

3. The petrographic work on metamorphic rocks from eastern Central Sulawesi by De Roever (1947) suggested two metamorphic facies: (1) an older intermediate P/T epidote-amphibolite facies, overprinted in the west by (2) high P glaucophane blueschist facies (generally associated with subduction zones).

III. GEOLOGICAL SURVEYS/ GEOLOGICAL MAPPING (1855-1930s)

III.1. The role of the Geological Survey (Dienst van het Mijnwezen) in Sulawesi since 1855

As had happened several times before in other areas, the Geological Survey/Bureau of Mines of the Netherlands Indies (Dienst van het Mijnwezen/ Dienst van den Mijnbouw) did not proactively conduct geological-mining surveys in poorly known areas of Sulawesi, but it limited its initial surveys to areas around existing native mines, or it waited until after private entrepreneurs had discovered mineral deposits of economic interest. In North Sulawesi, Mijnwezen personnel first arrived in 1885 when it requested by a private investor to evaluate gold occurrences in North Sulawesi, where native gold mining had been known since the early 1800s. This led to the surveys by Mijnwezen engineers Van Schelle in 1886 and Fennema/Koperberg in 1896-1906. Another example was the Mijnwezen evaluation of nickel deposits in the Verbeek Mountains of eastern Central Sulawesi in 1917-1922, after private explorer Abendanon had demonstrated their existence around 1910-1915 (see also below).

Unlike in Sumatra and Java in the 1920s-1930s, there never was a comparable systematic geological mapping program for Sulawesi by Mijnwezen. However, six multi-year Geological and Mining surveys (GMO, MGO) and a number of smaller surveys had been conducted between 1896 and 1930, which greatly enhanced the geological knowledge of large parts of Celebes (Sulawesi).

III.2. First geological-mining reconnaissance by Mijnwezen, North Sulawesi (1896-1906)

After private gold exploration and mining activities in North Sulawesi had rapidly increased in North Sulawesi in the 1890s, the Dienst van het Mijnwezen (Geological Survey) decided to support of the many small gold-mining operations here with a geological mapping project and regional assessment of the gold regions in the Menado and Gorontalo Residencies, in a project named the GMV Geologische en mijnbouwkundige verkenning van de Residentie Menado (Geological-Mining Investigations of North and Central Celebes project).

The North Sulawesi survey work in was started by R. Fennema and J.F. de Corte in 1896-1897. Unfortunately, Fennema accidentally drowned in Lake Poso during a survey in the western part of the Menado Residency in November 1897. After a year of hiatus, the project was resumed by Ir. M. Koperberg from late 1898 until early

1905, assisted by P. Hovig from 1903. Members of the project were based in Menado.

The results of the 10-year fieldwork project were compiled in a 3-volume, 840-page report entitled 'Building blocks for the geology of the Manado Residency' (in Dutch) (North and northern Central Sulawesi). It was compiled by Koperberg during his retirement in the Netherlands and was published more than twenty years after the survey work was completed (Koperberg, 1929; see more in Koperberg chapter in Van Gorsel 2022, vol. 2).

III.3. Sulawesi geological reconnaissance by R. Verbeek (1899)

During R.D.M. Verbeek's island-hopping Moluccas survey in March-December 1899, Verbeek made various brief stops in Sulawesi. The extensive Verbeek (1908) book and Atlas contain information on localities (briefly) visited by Verbeek, but also review earlier research around the areas visited. These included several North Sulawesi coastal locations in July, around Menado in early November and around Makassar in SW Sulawesi in mid-November (with an excursion to Maros-Pangkajene) (Verbeek, 1908).

The geological map compiled by Verbeek (1908) captures the geological knowledge after the works of Van Schelle, Koperberg, Bucking, Ahlburg,

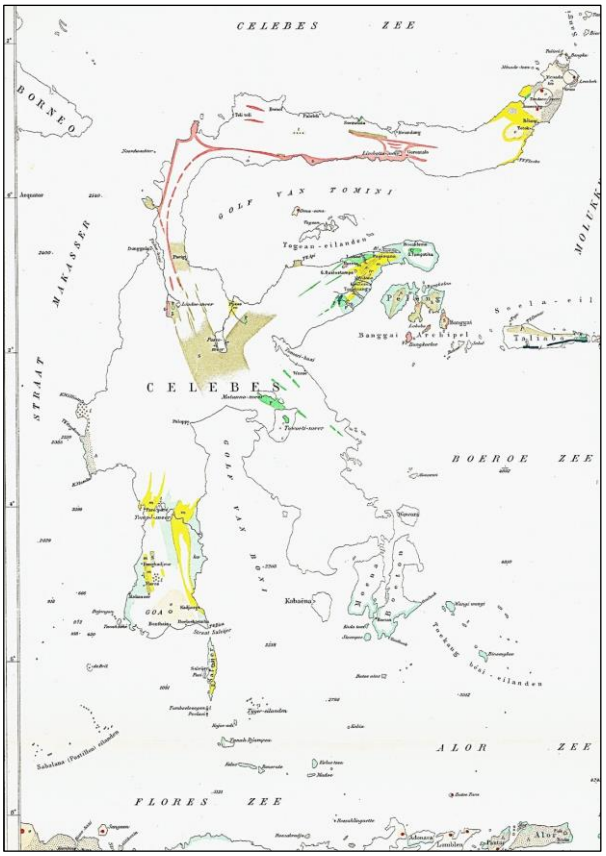

Figure 13. *Part of the geologic sketch map of the eastern Netherlands Indies by Verbeek (1908), showing that most of Sulawesi was still geologically unknown territory at that time. This was after the initial surveys of Van Schelle, Fennema/Koperberg, Wichmann, the Sarasin cousins, Wanner, Bucking and Ahlburg, but before Abendanon and the post-1908 works by the Geological Survey.*

the Sarasin cousins and himself, and shows how much of Sulawesi was still completely unknown at that time (Figure 13).

Although the Maros area in SW Sulawesi had been described several times before, Verbeek added some useful corrections to the work of Wichmann (1898), Bucking (1898) and the Sarasin cousins (1901). He documented that the famous Maros limestones contained both Eocene and Miocene larger foraminifera (like many other 'Tonasa Limestone' occurrences in other parts of Sulawesi, as would be established later) (Figure 14).

Geology of Selayar Island, south of the SW Arm of Sulawesi (1908)

One of Verbeek's most useful contributions to the understanding of Sulawesi geology was perhaps on the geology of islands near Sulawesi, like Salayar, and his interpretation of its geological history. Noting the relatively simple geology of West-dipping Miocene sediments and the fact that water depths East of Salayar rapidly deepened to 1000-3000, 20km to the East, Verbeek concluded that the East side of Salayar island had to represent a large normal fault. We know now how well this fits with Salayar being a rift shoulder at the western margin of the Neogene opening of Bone Bay and the Banda Sea.

III.4. Geological-mining projects by the Geological Survey (1909-1930)

The Dienst van het Mijnwezen/ Mijnbouw (Bureau of Mines/ Geological Survey of the Netherlands Indies) was created in 1850, but for the first four decades of its existence, projects in Sulawesi were probably limited to the brief investigation of coal in SW Sulawesi by Schreuder (1854) and the gold mining survey in North Sulawesi by Van Schelle in 1886 (see also above). The first more regional survey work by Mijnwezen was the Menado Residency fieldwork of 1896-

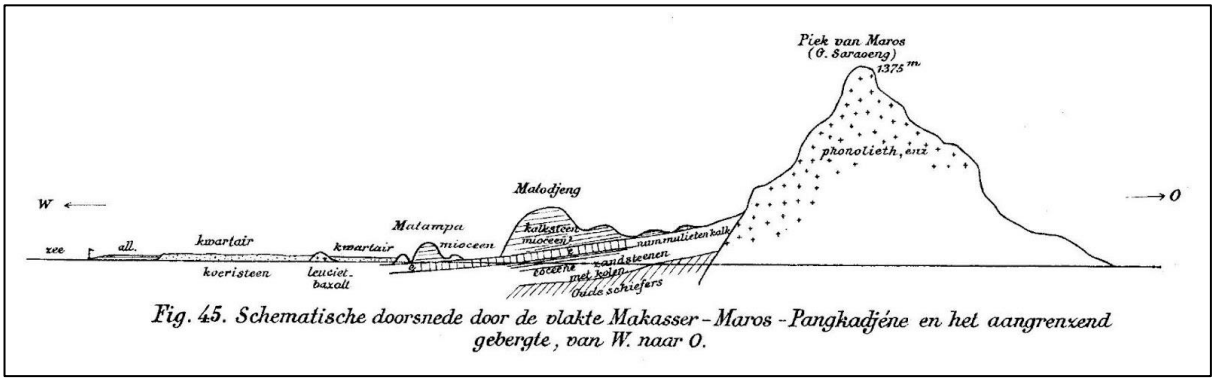

Fig. 45. Schematische doorsnede door de vlakte Makasser - Maros - Pangkadjéne en het aangrenzend gebergte, van W. naar O.

Figure 14. *Diagrammatic cross-section of Makassar Plain- Maros- Pangkajene and adjacent mountains in SW Sulawesi (Verbeek, 1908). It shows the west-dipping 'old schists' overlain by Eocene sands, coal and Nummulites limestone, overlain by Miocene limestone, intruded by the younger 'phonolith' of the Maros Peak. Some of this now-classic stratigraphy had been described earlier by Wichmann (1893), Bucking (1898) and the Sarasin cousins (1901).*

1906 by Fennema and Koperberg (see III.2, above).

From 1909 until 1930, Mijnwezen/ Mijnbouw was reasonably active in Sulawesi, with five significant geological-mining investigation projects. All this came to a halt after budget cuts during the 1930s, due to the global economic crisis. This was followed by non-activity during the Japanese occupation of 1942-1945 and the war of Independence in the late 1940s. During the first 2-3 decades after Indonesian Independence, little or no work was done in Sulawesi by the Indonesian Geological Survey, suffering from limited funding during the poor economic situation and lack o South f trained personnel after the loss of Dutch geological expertise.

Geological-mining reconnaissance and Central Sulawesi (1909), MO Celebes en Onderhoorigheden (1911-1917)

J. de Koning Knijff and H. Cool of the Dienst van het Mijnwezen (Geological Survey) conducted some reconnaissance surveys of South Sulawesi and the southern part of Central Sulawesi in 1909. Its results were summarized in De Koning Knijff (1914). It led to led to the creation of a large mining investigation project (MO) between 1911 and 1917, the MO Celebes en Onderhoorigheden. Its purpose was the evaluation of potential economic mineral deposits of Central Sulawesi, especially copper and iron ore. Key Mijnwezen personnel included J. van der Kloes, J. Reijzer, C.A.F. Macke and H. Wolvekamp. Its results were summarized in Anonymous (1920) and Reijzer (1920). The project failed to prove any commercially viable mineral deposits in Central and South Sulawesi.

Van Waterschoot van der Gracht, 1913

In 1913 W. van Waterschoot van der Gracht undertook two weeks of government-sponsored fieldwork in the Toraja lands, accompanied by Mijnwezen mining engineers/ geologists P. Hovig and J. Reijzer, mainly to investigate the stratigraphy. Its results were summarized in Van Waterschoot (1915, a, b). Van Waterschoot was critical of the earlier work by Ahlburg and Abendanon, while, in turn, his conclusions were heavily criticized by Abendanon (1915).

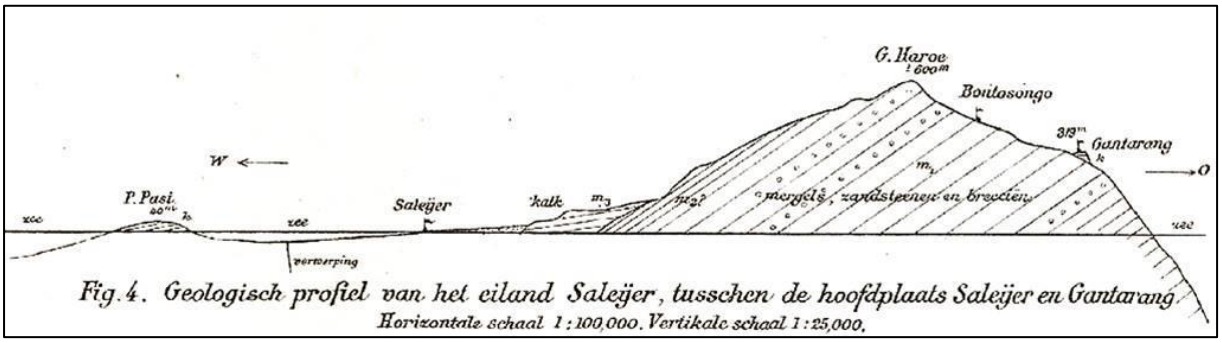

Figure 15. *West-East cross-section of Selayar island, showing 8-13 ° West-dipping ?Miocene sediments, correctly interpreted as a rift shoulder with a major normal fault on the East side (Verbeek, 1908).*

GMO Zuidelijk Celebes (South Sulawesi), 1913-1916

After the reconnaissance work of Wichmann, Bucking and the Sarasin cousins, the only significant work in the south (SW) Arm of Sulawesi was the multi-year Mijnwezen project by C.W.A.P. 't Hoen and K.G.J. Ziegler, who conducted fieldwork from December 1912 until March 1915 ('T Hoen & Ziegler, 1917; Figure 16). Rocks from the project were described by Von Steiger (1915).

The project provided new documentation of the Pretertiary complexes of steeply-dipping schists, unconformably overlain by Cretaceous greywackes. It also clarified the Tertiary stratigraphy of Eocene coal-bearing sandstones, Late Eocene Nummulites limestones and the late Tertiary volcanics. It included detailed maps of the Eocene coal fields Tondong Koerah, Podo, Batoekoe and Malawa, but the only time that these Sulawesi coals were exploited was during the Japanese occupation.

Worth mentioning here is a brief sampling trip in Sulawesi around the same time by American geologist-petrographer Prof. Joseph P. Iddings, who was on a mission to sample leucitic lavas around the world. In SW Sulawesi in 1914 he collected potassic lavas of the Maros Peak area and other areas formerly sampled by H. Bucking and R. Verbeek (Iddings & Morley, 1915).

GMO Verbeekgebergte (Malili), 1917-1922

This Mijnwezen project in the Verbeek Mountains of eastern Central Sulawesi from 1917-1922 was an evaluation of the iron, nickel and chromium deposits associated with the weathering of the large ultramafic complex of East Sulawesi, after these had just been discovered by E.C. Abendanon in 1910 (Abendanon 1915-1917, Dieckmann 1919, Dieckmann and Julius 1925). It was conducted mainly by J.W.H. Adam, M.H. Caron, W. Dieckmann, C. Macke, M. Julius and W. Benschop Koolhoven.

In an appendix of Dieckmann & Julius (1925), Van der Vlerk distinguished three groups of pelagic rocks which formed the sedimentary cover of the East Sulawesi ophiolite complex: red radiolarian chert (Jurassic-

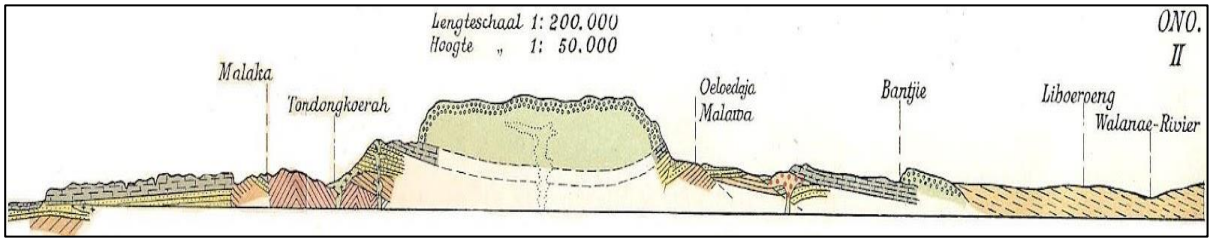

Figure 16. *Example of a WSW-ENE regional cross-section across SW Sulawesi ('t Hoen & Ziegler, 1917). With near Tondongkoera folded Pre-Tertiary metamorphics in pink. overlain by Eocene sandstones (yellow) and limestones (grey), and as topographically highest formation thick post-Eocene volcanics (light green).On right Late Tertiary sediments of the Walanae River valley.*

Cretaceous?), red shales with *Globigerina linneana* (= Late Cretaceous *Globotruncana*) and grey shale with Late Cretaceous or Early Tertiary planktonic forams. The report also contains petrographic descriptions by W.J. Gisolf.

GMO Oost Celebes en onderhoorigheden (East Sulawesi), 1922-1930

This project was a systematic geological-mining investigation of East Sulawesi and dependencies, with Buton island and its asphalt deposits as a focus area. The main members were J.J. Reijzer, W.C. Benschop Koolhoven, A.C.D. Bothe, W.H. Hetzel and H.E.G. Straeter. During the early part of the project in 1923 Koolhoven did a reconnaissance of the Banggai islands and the East Arm of Sulawesi (Koolhoven, 1930; Figures 17, 18). Later, Koolhoven expanded on the work of Dieckmann and Julius (1925) in the nickel-bearing peridotite terrains between the Towuti and Matano Lakes (Koolhoven, 1932).

During the late 1920s most of the team was based in Bau-Bau, Buton. The key

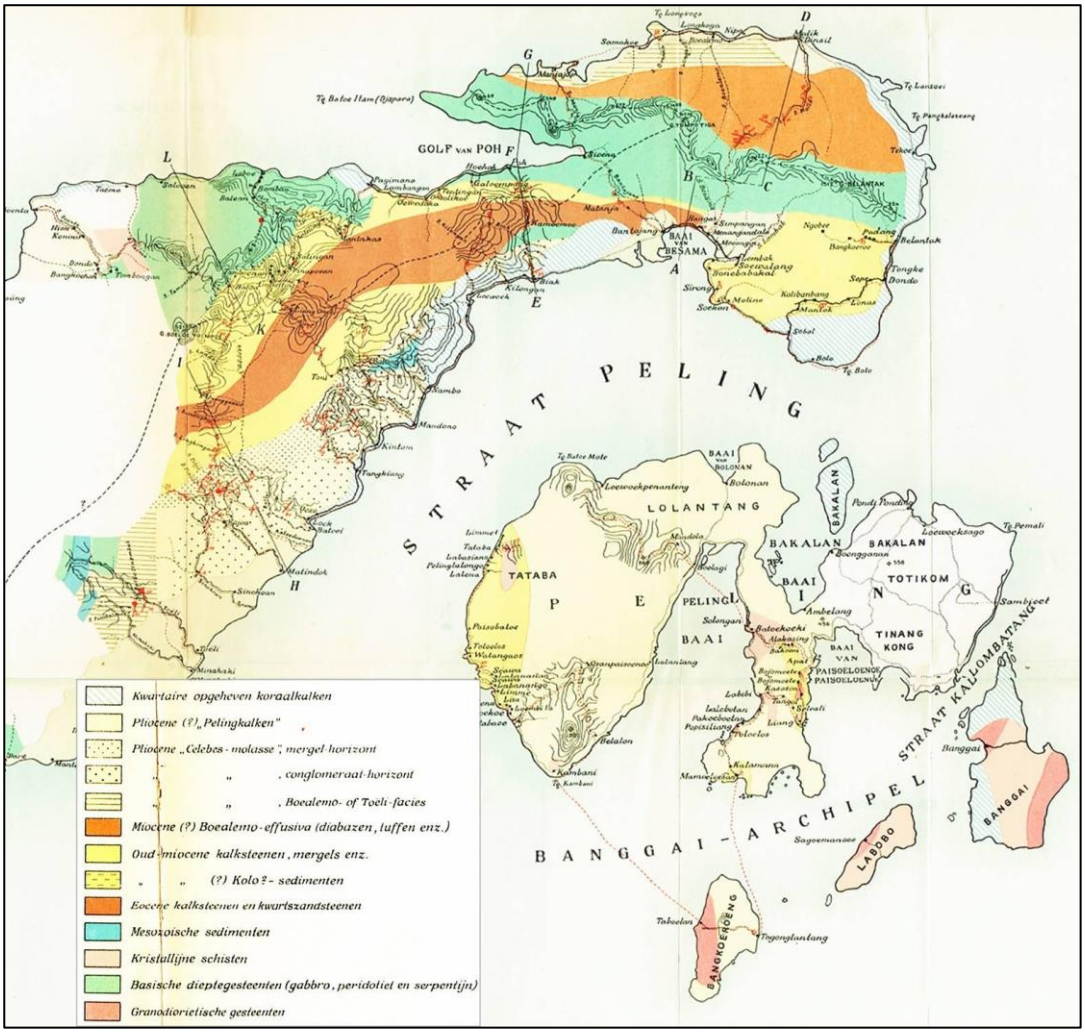

Figure 17. *Geologic map of the eastern part of the East Arm of Sulawesi (Koolhoven, 1930).*

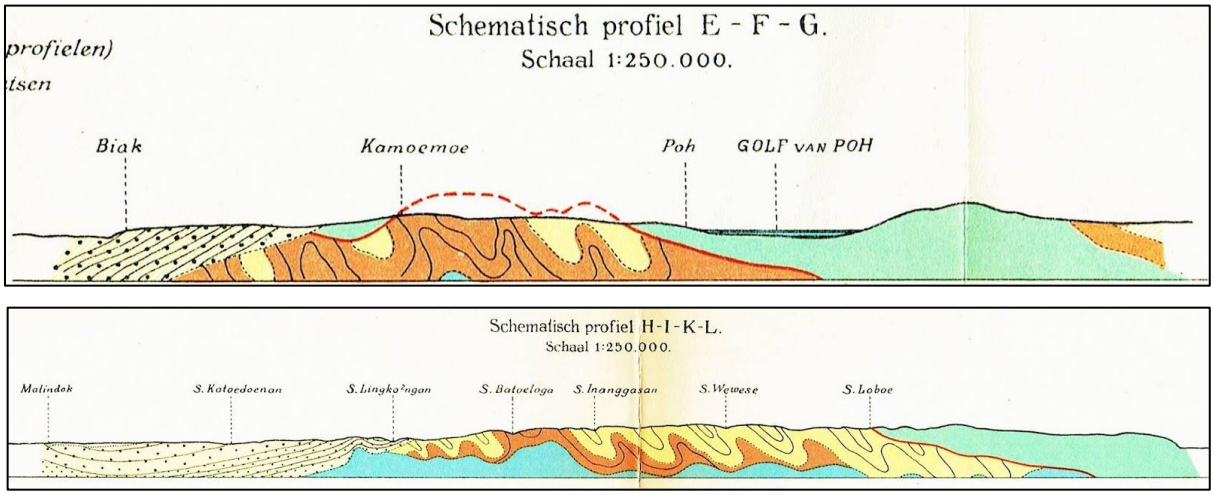

Figure 18. *Two south-to-north cross-sections across the eastern part of the East Arm of Sulawesi, E-F-G (top) and H-I-K-L (bottom) (Koolhoven, 1930). Both show a sheet of ultramafic igneous rocks (gabbro, peridotite, serpentinite) thrusted from the north over imbricated Mesozoic sediments and Eocene and Early Miocene limestones (= scraped-off sedimentary cover of the Banggai block margin). All Early Miocene and older rocks are unconformably overlain by Pliocene 'Celebes Molasse' in the south (left), which contains erosional detritus of ultramafics.*

reports from this time are by Koolhoven (1930) on the East Arm and Hetzel (1936) on the geology and asphalt deposits of Buton island.

IV. EARLY GOLD EXPLORATION AND MINING

The earliest gold diggings in parts of Sulawesi had been conducted possibly for centuries by native miners. After the first gold discoveries at Sumalata, North Sulawesi, in the early 1800s, the Netherlands Indies government signed a contract with the local rajah for annual deliveries of certain amounts of gold at a fixed price, but by 1846-1848 production from the native mines had virtually stopped (Von Rosenberg, 1878). The area would later become the site of European gold exploitation by the Mijnbouw Maatschappij Soemalata and the Kwandang Soemalata company from 1896-1908.

The first European interests in Sulawesi gold date back to the mid- and late 1800s. A significant increase of geological reconnaissance and prospecting for gold (and minor coal) in Sulawesi happened after the late 1880s until the 1920s, with a real 'gold rush' in the late 1890s (see also below).

IV.1. First gold prospects evaluation in North Celebes by Mijnwezen (1886)

The first 'official' investigation of gold occurrences in North Sulawesi by a government geologist was in 1886, when Mijnwezen mining engineer C.J. van Schelle surveyed an area with small native gold mining sites in the Gorontalo and Sumalata districts. This happened after a request for assistance in 1885 to Mijnwezen by J.A. Parmentier of the Gorontalo-based trading company Bauermann en Parmentier (and later gold concession

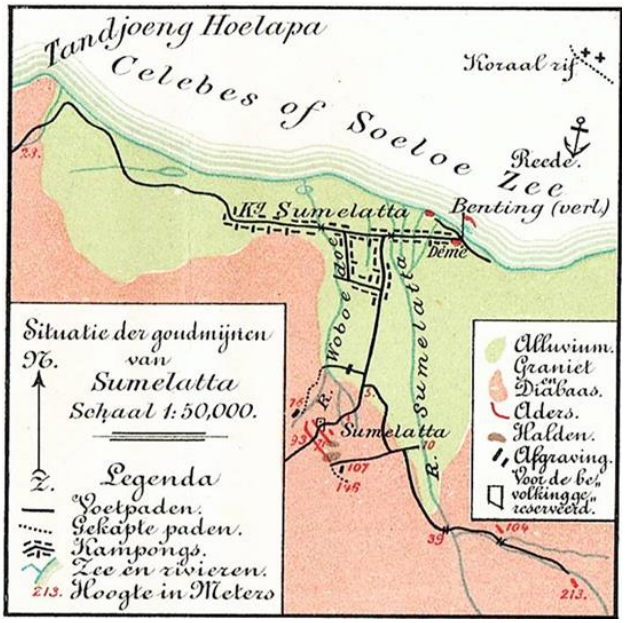

Figure 19. *Map around Sumelatta (Sumalata) on the north coast of North Sulawesi, showing locations of gold-bearing veins in red lines in the area of granite and 'diabase' (= andesite) (pink; Van Schelle, 1889).*

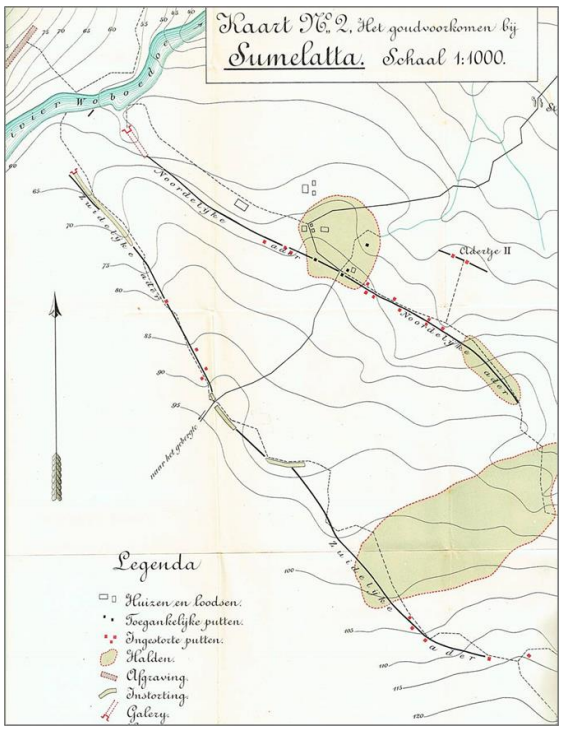

Figure 20. *Part of a map of the native gold mining operations at Sumalata (Van Schelle, 1889). Exploitation was along two NW-SE trending quartz vein systems,*

owners at Sumalata). Parmentier accompanied Van Schelle during the North Sulawesi survey in 1886 and around 1897-1904 was Director of the Exploratie en Mijnbouw Maatschappij Gorontalo gold mining company.

North Sulawesi at that time was still geologically virtual terra incognita, and the gold prospectors mainly focused on areas around the many small native gold mines that were already been operational there before. There were no reliable topographic maps and it rugged, was heavily forested, volcanics-dominated terrain with very few roads or paths, and with a very limited Dutch colonial government presence.

Van Schelle reported on the native diggings, with shafts down to 14m deep, following quartz-bearing gold veins. They had been operational at least since 1813 or earlier, under the direction of local rajahs. However, by the time of Van Schelle's visit in 1886, the native mining operations were already mostly abandoned (Figures 19 and 20; Van Schelle, 1889). Van Schelle characterized the geology of North Sulawesi as a mix of granite, diorite, andesite and Late Tertiary clastic sediments and limestones.

IV.2. First European gold mining by entrepreneur Dr. Hermann Siber, 1890s

Swiss lawyer/planter/entrepreneur Dr. Hermann Siber became the first successful gold miner in (North) Sulawesi, after his tobacco plantations in NE Sumatra failed commercially. He came to North Sulawesi in 1891,

possibly after reading the Van Schelle (1889) reports, which confirmed the presence of relatively widespread, small native gold diggings in the Sumalata and Gorontalo districts of North Sulawesi.

Siber was not a geologist, but he had a strategy to explore around older (mostly abandoned) native gold mines, then negotiate mining permits with the rajahs of the small kingdoms of North Sulawesi. Siber founded a series of gold mining companies and by the mid-1890s started mining operations at Bwool, Paleleh, Totok, Pagoeat and others. This then fueled the infamous, short-lived 'Sulawesi gold rush' around 1900, in which many small investors lost much of their money. Many of the North Sulawesi gold mines around 1900 were operated with English and Australian mining engineers.

Although the Siber-owned gold mines in North Sulawesi performed relatively well, they were probably only marginally economic and did not make Dr. Siber a wealthy man. He died of illness in Sukabumi in 1901, at age 41.

IV.3. The Sulawesi gold rush of the late 1890s

The initial successes and unrealistic estimates of gold reserves in North Sulawesi in the 1890s led to a speculation-driven 'gold rush' across the Netherlands Indies in the late 1890s. Truscott (1899) reported that 50 gold exploration companies formed in the Netherlands Indies between 1897 and 1898 (and many more would follow), mainly for small gold exploration ventures in Sumatra, Central Borneo and North Sulawesi. He noted that 'on the majority of properties nothing has been discovered'. By 1910 almost all of these speculative ventures had collapsed. For decades after that, small private investors were very reluctant to buy shares in new mining projects in the Netherlands Indies.

IV.4. Gold prospectivity evaluations for private entrepreneurs by visiting European academics (1898-1909)

Several highly regarded German and Dutch academic geologists were contracted by more serious private entrepreneurs for brief gold and coal evaluation surveys in Sulawesi, including H. Bucking (1898), F. Rinne (1898-1899), G. Molengraaff (1901) and J. Ahlburg (1909).

Prof. Hugo Bucking, SW and North Sulawesi (1898)

Prof F.C.B.H. Bucking from the University of Strasbourg in the Alsace (at that time part of Germany) visited the Netherlands Indies in 1898, as an advisor of the Amsterdam-based Mijnbouw- en Industrie Syndicaat of tobacco entrepreneur August Janssen. After advising on petroleum geological issues in NE Sumatra, Bucking visited SW and North Sulawesi in June-September 1898. He visited the active gold mines at Sumalatta and Paleleh, providing some good early insights into the geology of these parts. In July 1898 he climbed the Soputan volcano in North Sulawesi, after the Sarasin cousins had already done so in 1895 (and Rinne did the same in late 1898 or 1899 and Ahlburg in 1909).

Bucking's SW Sulawesi survey included various traverses in the hinterland of Pajangkene, presumably primarily for an evaluation of Eocene coal deposits, which he deemed to be 'of excellent quality'. Here he was the first to describe the (Bantimala) Cretaceous metamorphic basement complex with its mica-schist, glaucophane schist, etc., associated with serpentinites, and overlain by radiolarian cherts. Bucking (1899, 1904) also reported on the now well-known Miocene limestones of Maros, North of Makassar, and the underlying Eocene clastics with coal and overlying *Nummulites* limestones.

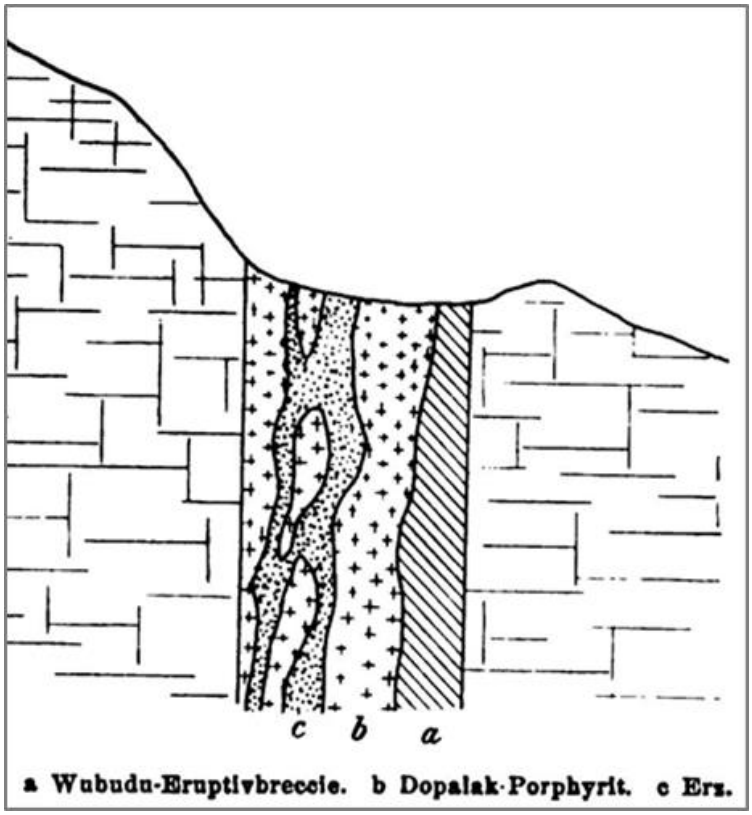

Figure 21. *Diagrammatic cross-section of a typical, vertical gold-bearing porphyrite intrusive into granitic rock and volcanic breccia, with gold-silver-lead-bearing sulphide ore (c), at Sumalata (interpreted as a fault zone; Molengraaff, 1902).*

Bucking also confirmed the presence of leucite-bearing basaltic rocks, first discovered in SW Sulawesi by Wichmann in 1888 (Wichmann, 1893). Bucking reported this rock from at the base of the Nummulites limestone, implying an Eocene age of the basalts, but 't Hoen and Ziegler (1917) considered it a much younger intrusion. In 1904 Bucking published an extensive paper on descriptions of rocks from Sulawesi sampled by Hoven, the Sarasins, Boehm and others.

Prof. F. Rinne (1898)

In the Fall of 1898 Prof. F. Rinne, Professor at the Technische Hochschule in Hannover, Germany, was commissioned by the Mijnbouw Maatschappij Oost Totok to conduct geological work in North Sulawesi, in the Minahasa (Kotabuna) and Gorontalo (Totok) districts. He published early petrographic descriptions of the volcanics-dominated rocks of the areas (Rinne, 1900).

Prof. G.A.F. Molengraaff (1901)

Seven years after his pioneering 1894 Central Borneo Expedition and while residing in South Africa (1896-1905) G.A.F. Molengraaff returned to the Netherlands Indies for a 4-month geological-mining survey near Sumalata at the North coast of North

Sulawesi, in June- December 1901. This was a consulting job for the Kwandang-Soemalata Mining Company, to evaluating gold-bearing veins. Like most industry work, this work remains mostly unpublished, except for a geological summary of the area in Molengraaff (1902; Figure 21)

J.H.W. Ahlburg (1909)

German geologist J. Ahlburg spent several months in Sulawesi in 1909, presumably on behalf of one of the gold mining companies, although the peak of the 'North Celebes gold rush' was over by then. Although his personal survey work covered only a limited area, Ahlburg did make a thorough effort of summarizing his and other geologists' work (Ahlburg, 1910, 1913) and even ventured into proposing a tectonic model of the island. Needless to say, his tectonic synthesis was somewhat premature, given the sporadic knowledge of the geology of Sulawesi at that time and its complexity.

V. PETROLEUM GEOLOGICAL SURVEYS

Many petroleum geologists conducted brief geological surveys across the Netherlands Indies, mainly as employees or contractors of the Koninklijke Olie (Royal Dutch; after the merger with Shell in 1907; subsequently operating as BPM), Their work tended to focus on Tertiary basinal areas ('follow the seeps'), but some also captured information on the geology of areas that were previously unexplored and proved to be non-prospective. Unfortunately, most of this oil company field geology work remains unpublished.

Early oil exploration in Sulawesi was unsuccessful. Several very shallow wells were drilled in the Lariang District of West Sulawesi (an area with oil and gas seeps) by the Exploratie Maatschappij Doda near Mamuju (Mandar) in 1898-1901, while the Bataafsche Petroleum Maatschappij (BPM/ Royal Dutch-Shell) conducted extensive geological field reconnaissance and prospect mapping in 1927-1938, in which surface anticlines were identified, but it is not clear if wells were drilled. No results of their surveys here were published. Several later rounds of oil exploration in West Sulawesi also did not lead to economic success.

Sulawesi geological surveys by mainly Swiss geologists of Royal Dutch/BPM included:

- M. Muhlberg (around 1902; probably in the SW or West Sulawesi area with oil seeps; unpublished);
- J. Wanner (1905) and H. Hirschi (1909) surveys of parts of the East Arm;
- W. Hotz (1912, NMMW survey of East Arm; mostly unpublished);
- E. Kundig and F. Weber (1927-1929; southern part of the East Arm);
- Von Loczy (1928; Tokala-Bungku traverse of the East Arm of Sulawesi);
- Horst von Bandat (1933-1935; Lariang/Pasangkayu/Mamuju Tertiary basinal areas in West Sulawesi).

First petroleum geological reconnaissance of the East Arm (1905-1912; Wanner, Hirschi, Hotz)

The East Arm of Sulawesi was long neglected by all travelers. Neither the Sarasins nor Abendanon bothered to include it in their expeditions. For some reason the little-known and structurally complex East Arm of Sulawesi attracted the interest of oil companies.

The first geological reconnaissance in the East Arm of Sulawesi was by German geologist Johannes Wanner, conducted a two-month geological survey in January-March 1905 on behalf of the Royal Dutch Petroleum Company ('Koninklijke') (Wanner 1910, 1914, 1919). This area had never been visited by Europeans, except perhaps by M. Koperberg during a 1903 survey in the west and by mineral prospector Reinier Verbeek (not the famous regional geologist Rogier Verbeek of Mijnwezen) during a little-known prospecting journey from Tangkian (Kintom) to Bunta a few months earlier (of which nothing was ever published).

J. Wanner mainly visited the SE side of the East Arm, along Peleng Straits, near Toeli, Nambo, etc. In and around the Central Mountains he described (1) ultrabasic rocks, (2) widespread Eocene limestones with *Alveolina*, *Discocyclina* and *Nummulites* (which he noted were reminescent of the *Alveolina* Limestone of Misool); (3) Early Miocene shallow water carbonates with *Lepidocyclina* and *Miogypsina*; (4) conglomerates of the Celebes Molasse (a name coined earlier by the Sarasin cousins), about 1200m thick, with sandy marls and limestone near its base containing latest Miocene-Pliocene planktonic and larger foraminifera (*Globorotalia tumida*, no lepidocyclinids), (5) Quaternary raised coral reef terraces up to 400m above sea level. Near Toeli, Wanner also described probably Jurassic-age 'Toeli Limestone', reminiscent of limestones Wanner had encountered on Buru Island. Along the North coast (Tomini Bay) Wanner found common gabbro and peridotite, with an oil seep in Babason creek. Wanner interpreted the gabbros as intrusions into Early Miocene limestone with *Spiroclypeus* and *Lepidocyclina* (Wanner, 1910), but these are now known as parts of the overthrust East Sulawesi ophiolite complex.

As a follow-up of Wanner's 1905 work in the eastern part, Swiss Royal Dutch geologist Hans Hirschi conducted a reconnaissance geological survey of the western part of the East Arm of Sulawesi in July-August 1909. Some of his results were summarized in a brief paper (Hirschi, 1913). Hirschi first trekked along the south coast of Tomini Bay from Todjo to Bongka and Tanjung Api. He then traversed the East Arm to the South, to Tomori Bay (the same route would be traversed by Abendanon in 1910), encountering peridotites, diabase breccias, and red radiolarites and shales. Closer to Tomori Bay he noted intensely folded Mesozoic limestones and peridotites.

In 1912 another Swiss geologist Walter Hotz visited the East Arm for the small

Dutch exploration company NMMW (which also employed L.M.R. Rutten), but his 1913 publication is quite brief and contains little news, except for his discovery of belemnites which proved the Mesozoic age of some sediments in the East Arm.

Second episode of East Arm geological surveys by BPM (1927-1929; Kundig, Von Loczy)

A second and more thorough episode of geological work by BPM in the East Arm of Sulawesi was in 1927-1929. Especially the works by Swiss geologist E. Kundig and Hungarian geologist L. von Loczy in East Sulawesi were thorough and exemplary.

Von Loczy reported on fieldwork in February-July 1928 in the Bongka River region of the western part of the Sulawesi East arm. 70% of area is covered by ophiolites (peridotite, serpentinite, gabbro), which he correctly interpreted as thrusted over folded Triassic- Lower Tertiary marine sediments (with local contact-metamorphism (Von Loczy, 1934). Von Loczy also significantly expanded the knowledge of the open marine Mesozoic stratigraphy here, which includes 300-500m of dense Late Triassic (Norian) limestones rich in Misolia, deep marine Late Jurassic belemnite limestone and white and red radiolarian-bearing Upper Jurassic-Cretaceous pelagic limestones. He also reported highly folded Late Eocene limestones with *Discocyclina* and *Pellatispira*, overlain by Miocene limestones. The youngest formation is the Celebes Molasse, 1200m thick, with Late Miocene *Lepidocyclina* limestone near its base.

Separate chapters on paleontology of Von Loczy's samples included reports on Upper Jurassic- Lower Cretaceous radiolaria (Hojnos), foraminifera (Van der Vlerk) and Mesozoic macrofossils (Kutassy). Some of Von Loczy's conclusions were debated by Hetzel (1935), Oostingh (1935) and Tan Sin Hok (1935).

Last but not least, two important papers resulting from the late 1920s BPM work in East and Central Sulawesi are by Kundig (1932, 1956); The Kundig (1932) paper was an early attempt at petrographic characterization of the metamorphic basement rocks of Sulawesi, in which he recognized areas of gneiss, phyllite, glaucophane schist, etc.

Kundig (1956) is an elegant review of the BPM fieldwork in East and Central Sulawesi in 1929-1930 by Swiss geologists E. Kundig and F. Weber, which incorporated the earlier data from Wanner (1905), Koolhoven (1930), Brouwer (1934) and Von Loczy (1934). (Figure 22; for the Kundig geologic map of East Sulawesi, see the Van Gorsel & Subroto Tanjung Api paper; this volume).

All of the late-1920s geologists who worked in the East Arm and in eastern Central Sulawesi (Kundig, Von Loczy, Brouwer) arrived at the same interpretion of the structural style of the area: alpine foldbelt-style imbricated Mesozoic-Tertiary marine sediments, overthrust from the North and West by a large ultramafic sheet. This can now be understood as the

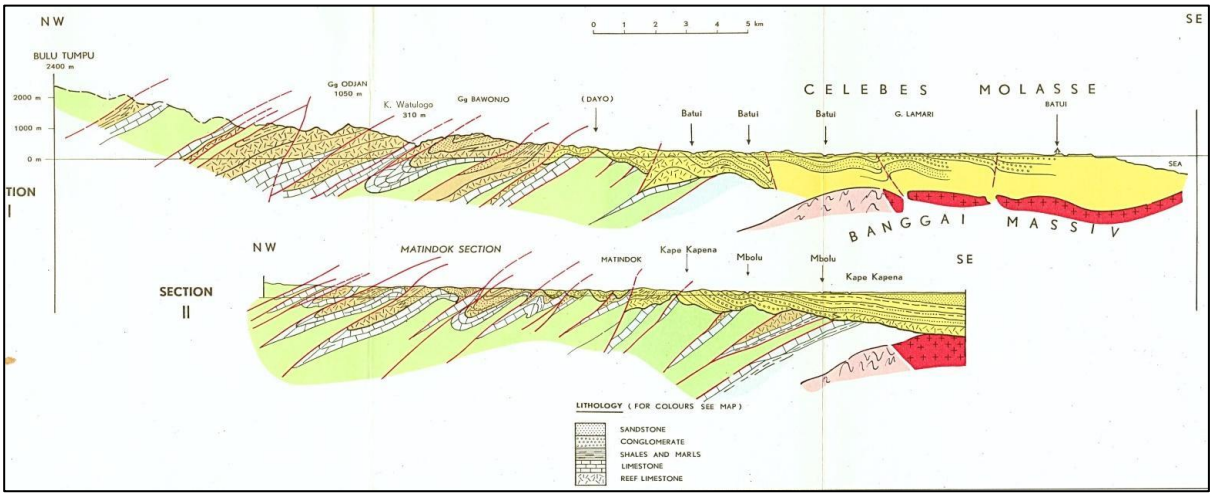

Figure 22. *Regional NW-SE cross-sections through the southern part of the East Arm of Sulawesi, based on BPM work in 1929-1930 (Kundig, 1956). It shows imbricated Jurassic-Cretaceous pelagic limestones (light blue) and Eocene-Middle Miocene limestones (tan) sediments (likely the sedimentary cover of the underthrusted part of the Banggai-Sula continental terrane). All rocks are unconformably overlain by Late Miocene-Pliocene post-orogenic 'Celebes Molasse' (yellow). In green is East Sulawesi Ophiolite, shown by Kundig as the oldest parts of the imbricated thrusts, but is more likely a separate overthrust sheet above the imbricated sediments*

scraped-off sediment cover of the Banggai-Sula plate ('Sula Spur') when it collided with (subducted under) Central Sulawesi.

VI. 'MODERN' TIMES (1970s-now)

Around 1930, interest in the geology and minerals of Sulawesi nearly completely collapsed, mainly due to the global economic recession. Although several important geological reports were still published in the 1930s until the 1950s, these were all based on pre-1930 fieldwork. No more field surveys were conducted in Sulawesi, with the exception of a few mineral evaluations by private companies and a relatively large evaluation program of nickel deposits in the Lake Matano area by the Billiton Maatschappij in 1940-1941 and in the late 1940s.

After a >40-year period of virtual dormancy, geological research and commercial exploration activities restarted in Sulawesi in the mid-1970s. Geological mapping by the Geological Survey of Indonesia was resumed mainly by Rab Sukamto and N. Ratman, who published several geological map sheets between 1975 and 1982, and later by T.O. Simandjuntak in the early 1990s. Other significant research by the Geological Survey in the 1990s was by Surono and others.

Minerals exploration by international mining companies was also resurrected in the 1970s, by Newmont, Rio Tinto, Kennecott, INCO, etc. The most prolific writer from the mining industry in Sulawesi since the 1980s was T. van Leeuwen. For more on mining activities in Sulawesi see Van Leeuwen & Pieters (2011, 2013). Oil

and gas exploration since the 1970 resulted in only a small number of small fields, mainly in Tertiary carbonates.

Foreign academic teams also entered the area in the late 1970s, including the University of London under the direction of Dr. A.J. Barber who conducted a series of geological fieldwork projects across Sulawesi with Ph.D. students, resulting in a series of important theses in the 1980s- early-1990s (T. Simandjuntak, A. Guntoro, C. Parkinson, K. Hasan, M. Wilson, etc.). Later this work continued under the direction of Prof. Robert Hall.

Other significant academic groups active in Sulawesi were French (Villeneuve, Cornee, Bellon, etc.;with Indonesian doctorate students B. Priadi, I. Syafri and Y.S. Yuwono), Australian (M. Elburg, Surono, S. Soeka), and Japanese (K.Wakita and others; with Indonesian doctorate students A.Kadarusman, A. Jaya, A. Maulana, Munasri and others).

For a more complete listing of the many contributors to Sulawesi geology, see the Bibliography of the Geology of Indonesia, Ed. 7.1 (www.vangorselslist.com)

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