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Three magnetometers from Australia's National Historical Collection

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This article significantly updates information first included in papers presented to the Scientific Instrument Symposium at Lisbon in 2008 and to a meeting of the Australian Society of Exploration Geophysicists at Canberra in 2009.

There are approximately 750 pieces of geophysical equipment in Australia's National Historical Collection (NHC) (Shephard 2013). The geomagnetic equipment in the collection includes variometers, aeromagnetic equipment and magnetometers.

This article will follow the working life of three Carnegie Institution of Washington (CIW) theodolite-magnetometers – CIW-7, CIW-16 and CIW-18 – from the collection. These were used in various places around the world before becoming part of the equipment of the Bureau of Mineral Resources, Geology and Geophysics (BMR). Together they illustrate the story of the four-decade 'magnetic crusade' of the Department of Terrestrial Magnetism (DTM) as well as subsequent geomagnetic research by the BMR and some of its predecessors. They were transferred to the National Museum of Australia for inclusion in the NHC in 1986, as part of a large collection of geophysical equipment covering the full range of BMR's activities.

They were associated with the work of several geomagneticians but this article will concentrate on only four: William Sligh in Central America, the Middle East and Africa; Earl Hanson in Africa; Robert Mansfield in Africa; and, Lew Richardson in Australia.

The Department of Terrestrial Magnetism

The task

The Carnegie Institution of Washington established DTM in April 1904 to investigate 'the magnetic and electric condition of the Earth and its atmosphere' on a worldwide scale (Fleming 1947, p. iii). Thus began a four-decade 'crusade' to extend the haphazard knowledge of Earth's magnetic field gathered by previous investigators. From its headquarters in Washington the DTM sent two vessels – the *Galilee* and the *Carnegie* – around the world's oceans, sponsored hundreds of land expeditions in some of the world's most remote places and established and operated two geophysical observatories at Watheroo (Western Australia) in 1919 and at Huancayo (Peru) in 1922 (Brown 2004).

Fig. 1. *Department of Terrestrial Magnetism's instrument workshop, 190?. Established in 1908 the workshop was under control of chief instrument maker Adolf Widmer. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

The land expeditions followed carefully selected routes through Africa, Asia, South America, China and Australia, establishing a co-ordinated system of stations at which the three elements of the magnetic field – declination, inclination and intensity – were determined and then regularly re-observed by subsequent expeditions. The expeditions of Sligh, Hanson and Mansfield, for example, all built on the work of previous magnetic observers. The purpose of this work was to establish a spatially and temporally co-ordinated set of data that could be used to mathematically analyse Earth's magnetic field to bring a greater understanding of it (Good 1994).

As well as conducting its own expeditions the DTM also provided training and equipment for others. Lew Richardson, for example, underwent training in DTM methods at Watheroo Magnetic Observatory before commencing his magnetic work for the Aerial, Geological and Geophysical Survey of Northern Australia.

The Equipment

The DTM's magnetic work in remote regions demanded a compact and portable instrument that could be quickly set up and read while maintaining the required level of accuracy. In the beginning the department purchased its magnetometers from established instrument makers, but from 1908-09 began constructing their own (Figure 1) (Carnegie Institution of Washington Year Book 1910).

The 'light portable type' of magnetometer they developed was enclosed in a timber case measuring 620 mm × 410 mm × 210 mm high that, when fully packed, weighed approximately 13 kg. Each individual component had its specific place in the case (Figure 2) and could quickly be assembled into an

Fig. 2. *Theodolite-magnetometer CIW-7. Image: National Museum of Australia, 2013.*

instrument that measured the three magnetic elements as well as astronomical elements. All this was achieved without any significant loss of accuracy. The instrument was improved on over time (Fleming 1911; Fleming and Widmer 1913).

The stories of CIW-7, CIW-16 and CIW-18 illustrate the usefulness of the DTM's instrument as well as the hardships and challenges faced by the magnetic observers who used them.

Theodolite-magnetometer no. 7 (CIW-7)

Theodolite-magnetometer CIW-7 (Figure 2), one of nine DTM-designed instruments assembled in the workshop of Bausch, Lomb and Saegmuller in New York, was acquired by the department in 1908 (Bauer *et al*. 1921). It was used briefly in Canada before being assigned to William Sligh who departed Washington in November 1908 on a three-year expedition that took him to Cuba, Central America, the Middle East, northwest Africa and Sierra Leone. Shortly after Sligh's return to Washington, the CIW-7 was sent to Watheroo Magnetic Observatory (Inventory Card for Magnetometer CIW-7).

William Sligh

Equipped with the CIW-7, a dip circle, pocket chronometer, watch and an observing tent, Sligh observed in Cuba, British Honduras (now Belize), Guatemala, Nicaragua, Honduras and El Salvador before returning to Washington in mid-1909, having occupied 45 stations. He had travelled by motor launch up the Belize River and by mule through the dense Guatemalan forest where progress was hampered by a lack of roads, swampy country, a scarcity of drinking water and inadequate shelter at night (Sligh 1912).

On Sligh's return to Washington, the CIW-7 underwent minor repairs to ready it for further field work. Sligh sailed from New York in December 1909 and arrived at Constantinople the following month. His equipment was the same as before but with the addition of a second watch. In the following six months he travelled a total of 22 300 miles by steamship, rail and pack animal through the Taurus Mountains and by raft down the Tigris River (Sligh 1915*a*, 1915*b*).

Fig. 3. *William Sligh at Malatia magnetic station, Anatolia, August 1910. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Eighty-four observing stations were occupied, including Beirut, Damascus, Madain-Saleh (the farthest point south Christians were allowed to travel), Kharput, Malatia (Figure 3), Baghdad, Basra, Muscat, Bombay (where the CIW-7 was compared to the Alibag Observatory's standard instrument), Aden, Port Sudan and Suez. Sligh suffered illness, including a bout of malaria at Damascus, and was placed in quarantine on three occasions – at Tebbok, Mush and Ramadieh.

The second stage of Sligh's work began in Cairo in the second half of 1911. Between June and November he travelled 13 600 miles by steamship, rail and sloop, observing at 46 stations in North Africa, the Canary Islands and along the west coast of Africa (Sligh 1915*c*). This stage of his work brought problems with climatic conditions, particularly with the wind, and with personal security.

At Algiers the observing tent was ripped to pieces by strong wind and had to be replaced by a locally made one. Wind was also an issue at Fuerteventura Island (Canary Islands) where, shortly before completing his work, the tent, equipment and observer were blown over by a violent gust. Fortunately no damage was done. More serious, however, was the threat of attack from local gangs along the West African coast. At Melilla, for example, a guard of four gendarmes and six soldiers was posted while observations were being made. In the event the party was not molested at any stage but the threat of civil unrest was always in the back of Sligh's mind – a concern shared by other DTM observers working in remote areas (see Hanson below).

Sligh returned to Algiers in early September and, after comparing CIW-7 at the observatory, he sailed for home reaching Washington in January 1913.

The CIW-7 now remained in store for six years, after which it was transferred to Watheroo Magnetic Observatory where it was installed as a standard instrument.

Watheroo Magnetic Observatory

The Watheroo Observatory was commissioned on 1 January 1919 (Fleming 1947). At the time it comprised two buildings for magnetic work – an absolute observatory and a variometer observatory – a hut for atmospheric, electric and earth-current apparatus plus ancillary buildings (Fleming and Wallis 1920). The absolute hut measured 5 m x 10 m with three piers at each end of the observatory for mounting a magnetometer, earth inductor and galvanometer (Figure 4). The installed equipment comprised the CIW-7, an earth-inductor 2 (Figure 5) and a galvanometer 2 (Figure 6), both manufactured by Otto Toepfer and Son of Potsdam in Germany.

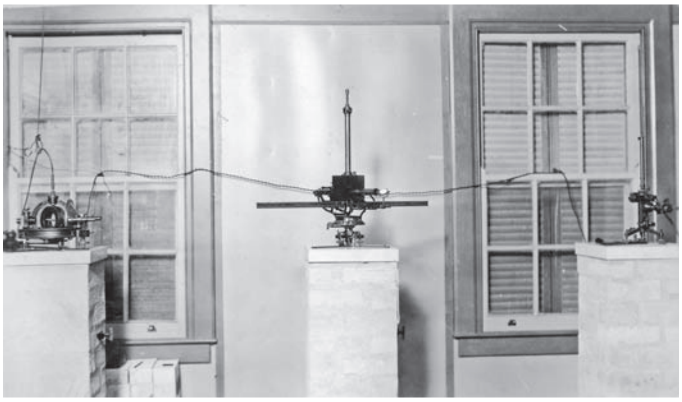

Fig. 4. *Watheroo Magnetic Observatory showing Toepfer earth-inductor no. 2, magnetometer CIW-7 and Toepfer mirror galvanometer no. 2, 25 May 1926. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

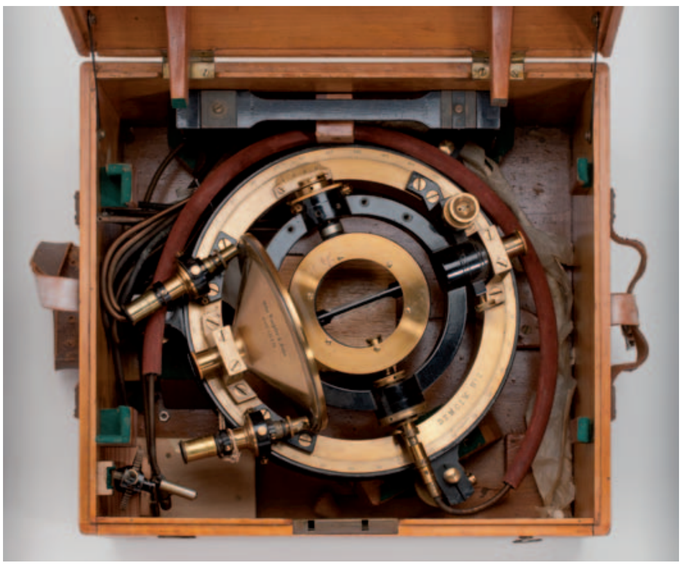

Fig. 5. *Toepfer earth-inductor no. 2. Image: National Museum of Australia, 2013.*

Fig. 6. *Toepfer mirror galvanometer no. 2. Image: National Museum of Australia, 2013.*

The fixed instruments were used to make absolute determinations of magnetic declination, inclination and intensity. At different times they were also used for comparison with field instruments, including the *Carnegie's* magnetometer in 1920 (Bauer *et al*. 1921) and the CIW-18 in 1935 (see below).

In July 1947, CIW gifted Watheroo Magnetic Observatory to the Australian Government and its operation was taken over by the BMR. It was closed in March 1959 and replaced by a new establishment at Mundaring, also close to Perth (McGregor 1979).

Unlike the CIW-7, the CIW-16 and CIW-18 remained field instruments for their whole working lives.

Theodolite-magnetometer no. 16 (CIW-16)

Theodolite-magnetometer CIW-16 (Figure 7) was assembled in the DTM workshop in May 1911 at a cost of US$650. It was used in Central America (1912 and 1940), South America (1912), Canada (1913), West Africa (1914–15 and 1922–27), South America (1919 and by Earl Hanson in 1931–33), on the Donald MacMillan Baffin Island Expedition (1921–22) (Figure 8), East Africa (by Robert Mansfield in 1934), on the Louise Boyd Arctic Expedition (1941), North America (1943) and at Huancayo Magnetic Observatory (1929–31 and 1946–48) before being written off the books in May 1949 (Inventory Card for Magnetometer CIW-16). When, how and why it came to Australia and where it was used here is still being investigated.

The Hanson and Mansfield expeditions shared experiences similar to those of Hanson but also illustrate some of the other field challenges faced by DTM's magnetic observers.

Earl Hanson

Earl Hanson departed New York in August 1931 and after some training in Cuba by J. W. Green moved to Venezuela in late

Fig. 7. *Theodolite-magnetometer CIW-16. Image: National Museum of Australia, 2013.*

September. From Caracas he travelled up the Orinoco River, crossed from its headwaters to the Rio Negro in the Amazon Basin and then, after observing at stations along the Amazon, moved to Bolivia and finally to Peru. He had travelled over 20 000 miles using a great variety of conveyances including steamers, launches, canoes, mules, horses, railroads, automobiles and trucks by the time he returned to Washington, via Ecuador and Colombia, in January 1932. Eighty-six field stations had been occupied and the CIW-16 compared with the standard instrument at Huancayo Magnetic Observatory (Hanson 1947).

Fig. 8. *Took-a-key viewing the azimuth mark with theodolite-magnetometer CIW-16 at Cape Dorset, Baffin Land, August 1922. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Fig. 9. *Earl Hanson at Valera magnetic station, Venezuela, 31 October 1931. Note canvas observing tent. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Hanson is unique in that he published a popular account of part of his South American expedition (Hanson 1938) in which he described the challenges and hardships of travelling and observing in the jungle regions of South America. Summarising his experiences he wrote 'I thought that a magnetic expedition would have been a lot of fun but for the need for observing the Earth's magnetism' (Hanson 1938, p. 301). More than a simple account of his geomagnetic work, however, his book commented on developmental issues in the countries he visited, thus anticipating his future career in regional development work in Latin America.

Hanson's task was to observe at monuments that had been established by previous observers as well as to establish new ones where necessary. Each provided its own difficulties. Many of the original monuments had been overgrown by vigorous jungle growth, villages had been abandoned and some had been deliberately destroyed by locals. At Guajara Mirim (Brazil), for example, the station site had been turned into a park. The president of the municipality assured Hanson that the replacement would not only be left alone, but would be considered as one of the features of the park (Hanson 1947).

Many of the sites originally proposed for new monuments proved unsuitable when examined in the field. At La Ceiba (Venezuela), for example, the proposed site was found to be a deep jungle-covered swamp. The station was eventually established at Valera (Figure 9), an overnight stopping place for buses and trucks on the main trans-Andean highway (Hanson 1947).

Illness and weather conditions also combined to hamper Hanson's work. At Caracas he suffered from a combination of a bad cold, indigestion and inflamed eyes, malarial attacks were frequent and at Porto Velho (Brazil) and Tres Unidos (Peru) his feet and legs were so infected from insect bites that he was unable to observe in the hot sun. The rugged country, heavy rain and flooded rives made travel difficult and on occasions damaged his instruments. Finally, like Sligh, he was concerned about civil unrest, including 'a bit of a revolution' in Cuba and the presence of a 200-strong gang of river pirates in Brazil (Hanson 1947, p. 27).

Following its return to Washington, the CIW-16 was in store or at Huancayo Observatory CIW-16 before being issued to Robert Mansfield for work in East Africa.

Robert Mansfield

Robert Mansfield was working at Huancayo Magnetic Observatory when commissioned to carry out work in southern and eastern Africa. He left Peru in April with equipment comprising the CIW-16, two pocket chronometers, two watches and an observation tent to begin work in Cape Town. Over the next 15 months he travelled 33 000 miles by ship, rail and motor vehicle to make observations at 60 stations in the Union of South Africa, Portuguese East Africa, Southern Rhodesia, Northern Rhodesia, Zanzibar, Tanganyika, Uganda, Kenya, Aden, Anglo-Egyptian Sudan, Egypt, Libya, Tunisia and Algeria. With his African work completed Mansfield travelled to Niemegk in Germany and Abinger in England before returning to Washington in August 1935 (Mansfield 1947). Many years later he reminisced about his experiences in an undated typescript that is now held in the DTM archives (Mansfield n.d.).

At first, Mansfield's work proceeded well but in July, at Pessene (Mozambique), disaster struck when the CIW-16 was badly damaged. He recorded the incident in his report

> *The shelter over the observing pillar, an arrangement with four large cement columns topped by canvas, collapsed for no obvious reason just as the magnetic instruments were being set up under it. The central base of the magnetometer was caught in the fall and thereby was damaged to such an extent that it could not again be used.* (Mansfield 1947, p. 50)

Fortunately he was able obtain a replacement – the CIW-18 – at Tabora Meteorological Station in Western Tanganyika (now Tanzania), after a 10-day trip by boat and rail. Thus, the rest of Mansfield's work is discussed below.

Theodolite-magnetometer no. 18 (CIW-18)

The CIW-18 (Figure 10) was assembled in DTM's workshop in 1916 and used in China (1916–17), East Africa (1930–34) and Australia (from 1935). Its use between 1917 and 1930 is not clear at the moment (Inventory Card for Magnetometer CIW-18).

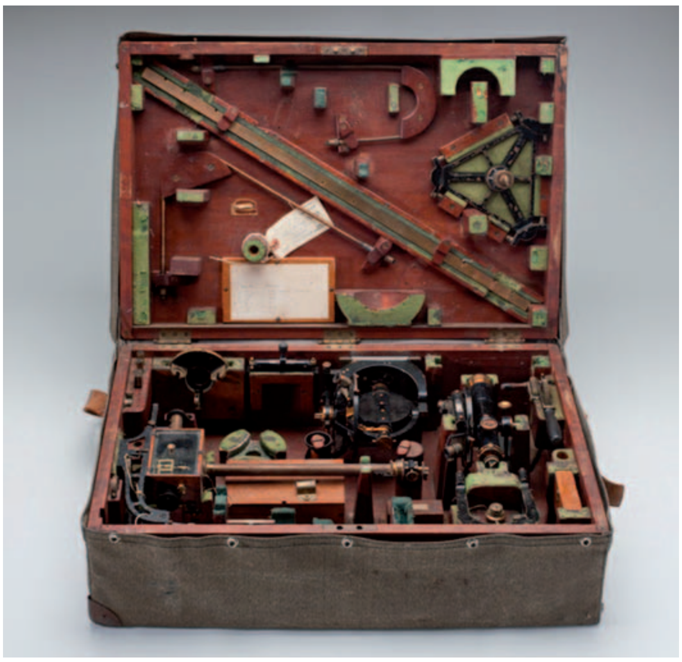

Fig. 10. *Theodolite-magnetometer CIW-18. Image: National Museum of Australia, 2013.*

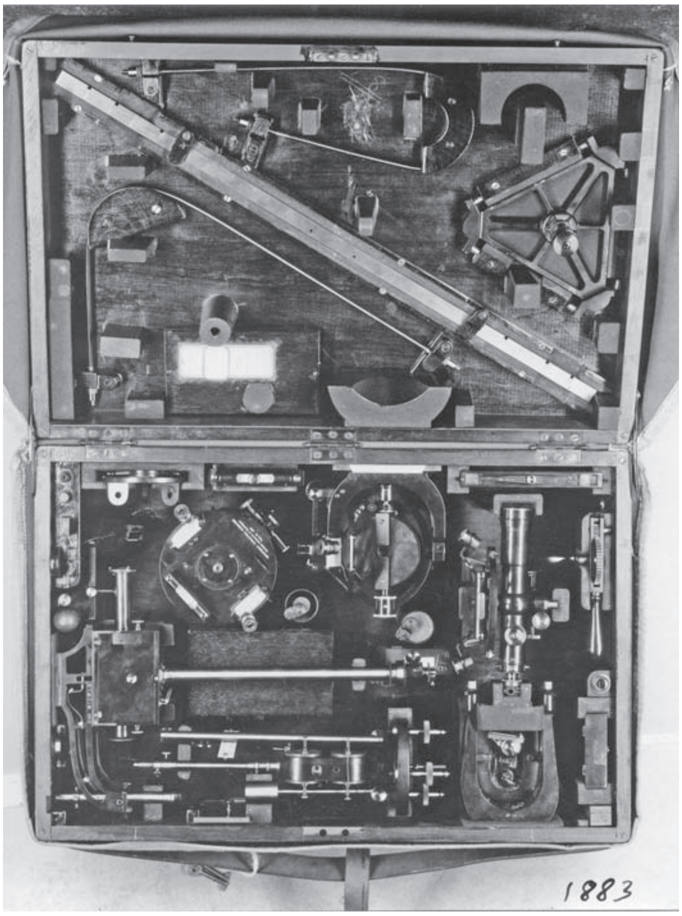

Fig. 11. *Theodolite-magnetometer CIW-18, as sent to British East African Meteorological Service at Nairobi in May 1930. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Early in May 1930, the CIW-18 was issued to the British East African Meteorological Service (Figure 11) at Nairobi (Kenya) for use in a planned extensive observing program in East Africa. Some problems were experienced with the standard observation tent – observing was never done without a sun helmet and in the old tent it was difficult to get around the instrument – so that it was replaced by a locally made one (Walter 1947). Subsequently it was loaned to 'Teddy' (later Sir Edward) Bullard who, together with his wife, made magnetic observations with the CIW-18 while carrying out a gravity survey in the Rift Valley (Bullard 1947). Subsequently it was transferred to Robert Mansfield in September 1934 to continue his African work.

Robert Mansfield (continued)

Having obtained the CIW-18 as a replacement instrument, Mansfield re-commenced his work, at Nairobi. The remainder of his expedition proved largely uneventful. On Zanzibar (Unguja) Island a contingent of police was needed to control curious onlookers while he established a new station behind the old Sultan's Palace at Chukwani (Figure 12). The African work was finished by the end of March 1935 and although he experienced some bureaucratic difficulties when landing his instruments in Egypt Mitchell was able to return to Washington by August 1935 (Mansfield 1947).

Fig. 12. *Chukwani magnetic station, Zanzibar, 2 October 1934. Image: Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2013.*

Fig. 14. *Dent chronometer no. 53862. Image: National Museum of Australia, 2008.*

The CIW-18 story now shifts to Australia and to Lew Richardson and the Aerial, Geological and Geophysical Survey of Northern Australia.

Lew Richardson

The Aerial, Geological, and Geophysical Survey of Northern Australia (AGGSNA) was established in 1935 to 'investigate the mineral possibilities of the less known and less accessible parts' of Western Australia, the Northern Territory and Queensland (Report...30 June 1935, p. 13). It combined geological, geophysical and aerial survey work and operated from 1935 to 1940, although work in Western Australia ceased in 1938. The geophysical work included electrical, electromagnetic, gravimetric and seismic work, as well as a magnetic survey party, under leadership of Lew Richardson, which operated from 1935 until the end of 1937 (Report...31 December 1938, p. 71). Richardson was issued with the CIW-18 after receiving instruction on its use and DTM methods at Watheroo. His other equipment included two Watts vertical force variometers – 15887 (Figure 13) and 15977 – and one Watts horizontal force variometer – 16165.

Richardson's work is detailed in the six-monthly reports of the AGGSNA, while John Rayner has written about the work of the survey (Rayner 2007), particularly concentrating on the role played by Jack Rayner, chief geophysical consultant to the survey. Richardson worked mostly at Tennant Creek but also at Wiluna in Western Australia and at Herberton, Croydon and Blair Atholl in Queensland. He also re-occupied several DTM magnetic stations.

Richardson continued using the CIW-18 after the end of AGGSNA, including investigations for the Royal Australian Air Force and Royal Australian Navy at Sydney (1943), Brisbane (1944), Fremantle (1944) and Darwin (1944). In 1944 he left Canberra on a 4½-month field trip that took him overland to Perth and by plane to the north-west coast. His equipment included the CIW-18, Watts vertical and horizontal variometers and a chronometer. A total of 33 magnetic stations were occupied with new ones being marked with a concrete block 300 mm long with a diameter of 115 mm, sunk flush with the surface of the ground. At each station, variometer observations were made at surrounding points to investigate the uniformity or otherwise of the magnetic field. The CIW-18 was compared with the standard instrument – the CIW-7 – at Watheroo before the party returned to Canberra, observing at stations on the way (Richardson 1947).

Fig. 13. *Watts variometer no. 15887. Image: National Museum of Australia, 2007.*

Fig. 15. *Brockbank & Atkins marine chronometer no. 1437. Image: National Museum of Australia, 2008.*

Fig. 16. *Canvas cover to CIW-18. Stickers include 'QANTAS/AIR/CARGO/PORT MORESBY', indicating that it was used in Papua New Guinea toward the end of its working life. Image: National Museum of Australia, 2013.*

Richardson experienced problems with his Roskell chronometer – on loan from the University of Adelaide – which was replaced by the DTM's Dent No. 53862 (Figure 14) from Watheroo. This chronometer had previously been on the *Galilee* (1906–08) and the *Carnegie* (1909–21), after which it was transferred to Watheroo in May 1925 (Inventory Card for Dent Chronometer 53862). The Dent was used from September to November on the return trip from Perth to Canberra.

The CIW-18 was subsequently used by Noel Chamberlain on the Cocos-Keeling Islands together with Watts vertical force variometer 15887 and Brockbank and Atkins chronometer 1437 (Figure 15) in 1946 (Chamberlain 1960), on Heard and Macquarie islands and on Iles de Kerguelen, again with Brockbank and Atkins chronometer 1437 in 1948 and 1950 (Jacka 1953) and in Papua New Guinea (Figure 16).

Conclusion

These three DTM magnetometers have been joined in Australia's National Historical Collection by other instruments they were associated with during their working lives – Dent chronometer 53862, Brockbank and Atkins chronometer 1437, Watts variometers 15887 and 16165 plus Toepfer earth inductor and galvanometer 2. Both individually and collectively, these instruments provide a significant representation of Australia's and the world's geoscientific heritage.

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