HARTLEY TRAVERS FERRAR (1879–1932) AND HIS GEOLOGICAL LEGACY IN ANTARCTICA, EGYPT AND NEW ZEALAND

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ABSTRACT

Hartley Travers Ferrar was the geologist on Scott's first expedition to the Antarctic (the 'Discovery' Expedition) in 1901–1904. Ferrar undertook the first geological surveys in the Transantarctic Mountains, which he mapped to 83ºS, and made some discoveries of major scientific importance, such as fossil leaves, later identified as *Glossopteris indica*. He then worked in Egypt, Palestine and New Zealand, and was Acting Director of the New Zealand Geological Survey when he died suddenly in 1932. Little has been acknowledged about Ferrar's other contributions to geology, which were vast, and included pioneering work on irrigation and hydrogeology in Egypt, as well as a series of geological mapping campaigns in New Zealand. The latter extended to systematic soil surveys in New Zealand, in particular in Central Otago, where soil types and their properties were characterized in the field and laboratory. This paper outlines some of Ferrar's key contributions to New Zealand geoscience, as well as some of his notable overseas achievements.

Keywords: Antarctica, Discovery Expedition, New Zealand, Egypt, geological mapping
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1. INTRODUCTION

Hartley ('Harry') Travers Ferrar (Figure 1) was born in Dalkey, Ireland on 28 January 1879. He spent much of his early life in South Africa, where his father became a bank manager, after first prospecting for gold and diamonds. He returned to the United Kingdom for his education at Oundle School in Northamptonshire, followed by studies at Sidney Sussex College, University of Cambridge. He went up to Cambridge in 1898 having been awarded a sizarship, and in 1901 was awarded honors in the Natural Science Tripos (Henderson 1932). He excelled at several sports, and was a champion at school, winning many cups and becoming Captain of the School as well as Captain of Boats and Football (Smith 1933). Ferrar is probably best known as the geologist on Captain Scott's first Antarctic Expedition (1901–1904, the 'Discovery' Expedition), where he was the youngest member of the scientific staff and of the Officers' Mess. With two seamen, William Weller and Thomas Kennar, Ferrar was the first to explore the glacier, which now bears his name. He then had a prominent career with the Egyptian Geological Survey, before making a significant contribution to New Zealand geology and soil science. He died in Wellington on 19 April 1932, and was survived by his widow and four children. Here we outline a selection of his achievements and contributions, together with some intriguing aspects of his life, particularly his experiences in Antarctica, Egypt and New Zealand.

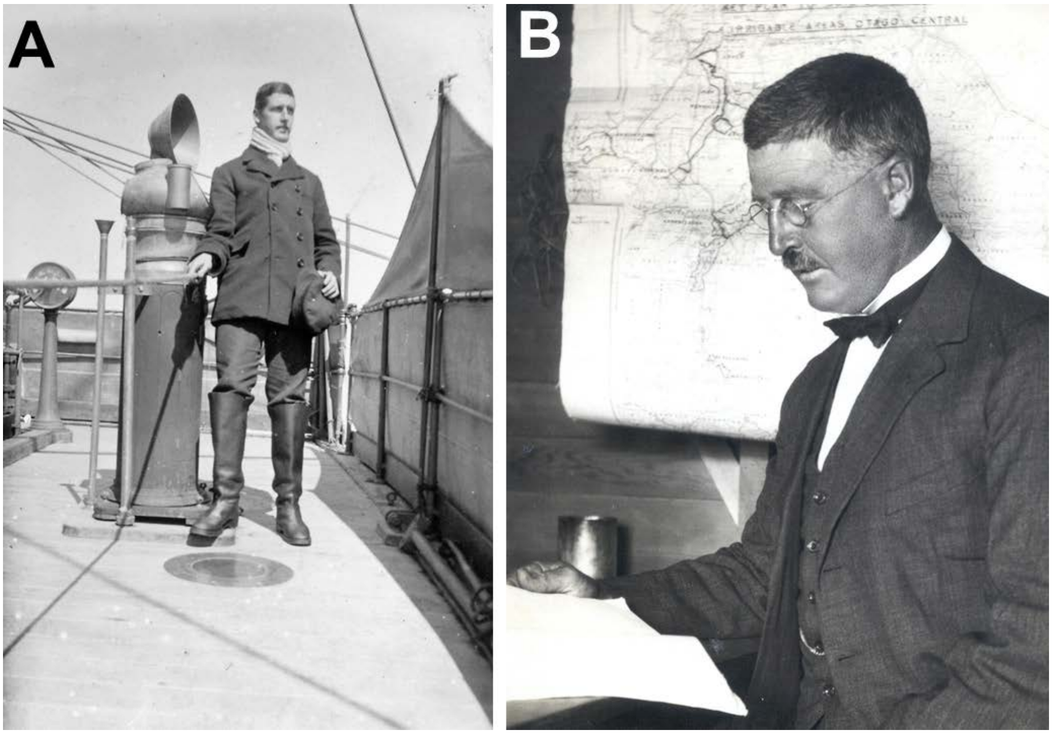


Figure 1: Hartley Travers Ferrar (A) on the Discovery *in Antarctica and (B) at work undertaking soil surveys in Central Otago (*circa *1928).*

2. FERRAR AND THE 'DISCOVERY' EXPEDITION TO ANTARCTICA

Ferrar was competing at the 1901 Henley Regatta when the telegram arrived informing him that he had been appointed the geologist on the National Antarctic Expedition. Hence, having graduated in June 1901, on 31 July 1901, Ferrar set sail on the RSS *Discovery*. He was a young Irishman who had grown up in South Africa onboard what was effectively a Royal Navy ship. He was an unproven, un-published, newly graduated scientist, alongside nearly fifty men with vastly more experience of sailing, and of life in general, than him. Ferrar's cabin was a small one amidships, a placing that underlined his position on board. Originally, Professor John Walter Gregory was to be the director of the civilian scientific staff of the National Antarctic Expedition (NAE) but in the planning stages Gregory was compelled to resign upon learning that he would be outranked by the expedition's commander, Captain Robert Falcon Scott (Leake 2011). Thus, by the time Hartley Ferrar was recruited, the job of geologist had become a very lowly one indeed, but he was young, strong and able to survive being the butt of jokes. Ferrar read studiously during the voyage, with Scott later recalling that despite the short timeframe from graduating to his appointment as expedition geologist, Ferrar:

> did his best to make up for this deficiency by a steady application to his books and an increased activity when he arrived . . . (Scott 1905, p. 70).

RRS *Discovery* arrived in Lyttelton, New Zealand, on 30 November 1901 and went into dry dock. During this time, Ferrar met his future wife, Gladys Anderson, granddaughter of John Anderson, mayor of the nearby city of Christchurch. The expedition then sailed south, arriving in McMurdo Sound in January 1902, where the crew carried out research until setting sail from Antarctica on 17 February 1904. On 8 February 1902 *Discovery* anchored in a site they named Winter Quarters Bay, where they built huts on the end of a rocky peninsula (now named Hut Point

Peninsula). This is a long, narrow peninsula 3 to 5 kilometers wide, and 24 kilometers long, extending south-west from the slopes of Mount Erebus on Ross Island (Figure 2). Scott Base (NZ) and McMurdo Station (US) are today located on the Hut Point Peninsula.

Ferrar's relative youth and inexperience when surrounded by navy personnel meant that his time in Antarctica, while scientifically successful, must have occasionally been challenging. For example, Lieutenant Reginald Skelton, the Chief Engineer, noted disapprovingly of how Lieutenant Albert Armitage, the second in command, spoke to Ferrar in front of the men:

> Wednesday 3rd December 1902: Armitage talks to him [HTF] in a most absurd way, a sort of bullying or ridiculing tone, in front of the men. Very bad form I think &, as I told Koettlitz [Dr. Reginald Koettlitz, physician and botanist of the expedition], I wouldn't stand it, but then he knows better than to speak like that to anybody who 'knows the ropes' . . . The doctor makes young Ferrar fly around . . . (Skelton 2004, p. 138).

It appears that Ferrar immersed himself in his work and this may at times have kept a reasonable barrier between himself and the likes of Armitage. Scott noted that Ferrar was rarely to be seen between meals, and was busy undertaking field mapping, field experiments, or laboratory experiments such as the deformation of ice samples on board the *Discovery*:

> Out on the hillsides and on the floes signs of him can be observed . . . on board one may see a shaft of ice bending under a weight with a notice 'do not touch – H.T. Ferrar' . . . I rarely meet Ferrar in my walks, and yet cannot speak of any feature of the numerous hill-slopes and valleys . . . without finding out that he knows it well . . . (Scott 1905, p. 314).

Indeed, Ferrar was very busy over the two years he was mainly based out of Hut Point, often pushing himself to his physical limits. On one occasion, he was returning to camp after one expedition and he collapsed several times in –45ºC temperatures. He was saved by Seaman William Heald, who kept him moving. On reaching camp on 26 September 1902, Ferrar was diagnosed with scurvy (Scott 1905, p. 541). Ernest Shackleton, who was the third officer on what was his first polar expedition, was also suffering from scurvy. Shackleton left McMurdo Sound on the relief ship, SY *Morning*, on 2 March 1903. In a letter to his mother dated 26 February 1903, Ferrar wrote:

> I thought of returning to New Zealand, but it looked as if I was 'funking' it, and I was advised not to. Poor Shackleton who is returning is very cut up about it. (SPRI MS 1785/5).

Ferrar recovered sufficiently to take part in further expeditions and in November 1903, he crossed McMurdo Sound and traversed what was then called the New Harbour Glacier, the largest glacier known at that time in Antarctica. The glacier was later renamed Ferrar Glacier in his honor. Ferrar Glacier is an outlet glacier that drains Taylor Dome in Southern Victoria Land (Figure 2). It is about 65 kilometers long, and flows from the plateau of Victoria Land west of the Royal Society Range to McMurdo Sound. Ferrar Glacier flows northeast of Knobhead, continues east along the south side of the Kukri Hills to McMurdo Sound. Ice flows into Taylor Glacier from both Cassidy and Ferrar Glaciers, with the latter contributing ice in two locations, Windy Gully and the Taylor-Ferrar confluence (Figure 2B). The age and paleoenvironmental significance of glacial landforms around the Ferrar Glacier remain important into the twenty-first century (e.g. Staiger *et al.* 2006). The nature of the relationship between the Ferrar and Taylor Glaciers still captured Ferrar's interest years after he returned from the *Discovery* Expedition. Indeed, in September 1913, Ferrar wrote a letter to Griffith Taylor (1880–1963), who had recently returned from Scott's *Terra Nova* Expedition to Antarctica.

Taylor had been contracted by Scott as senior geologist to that expedition. Like Ferrar on the earlier *Discovery* Expedition, Taylor was responsible for the first maps and geological interpretations of significant areas of Antarctica. In January 1911, Taylor had led an expedition to examine the area of the Dry Valleys and Ferrar Glacier in more detail, and gave the name Taylor

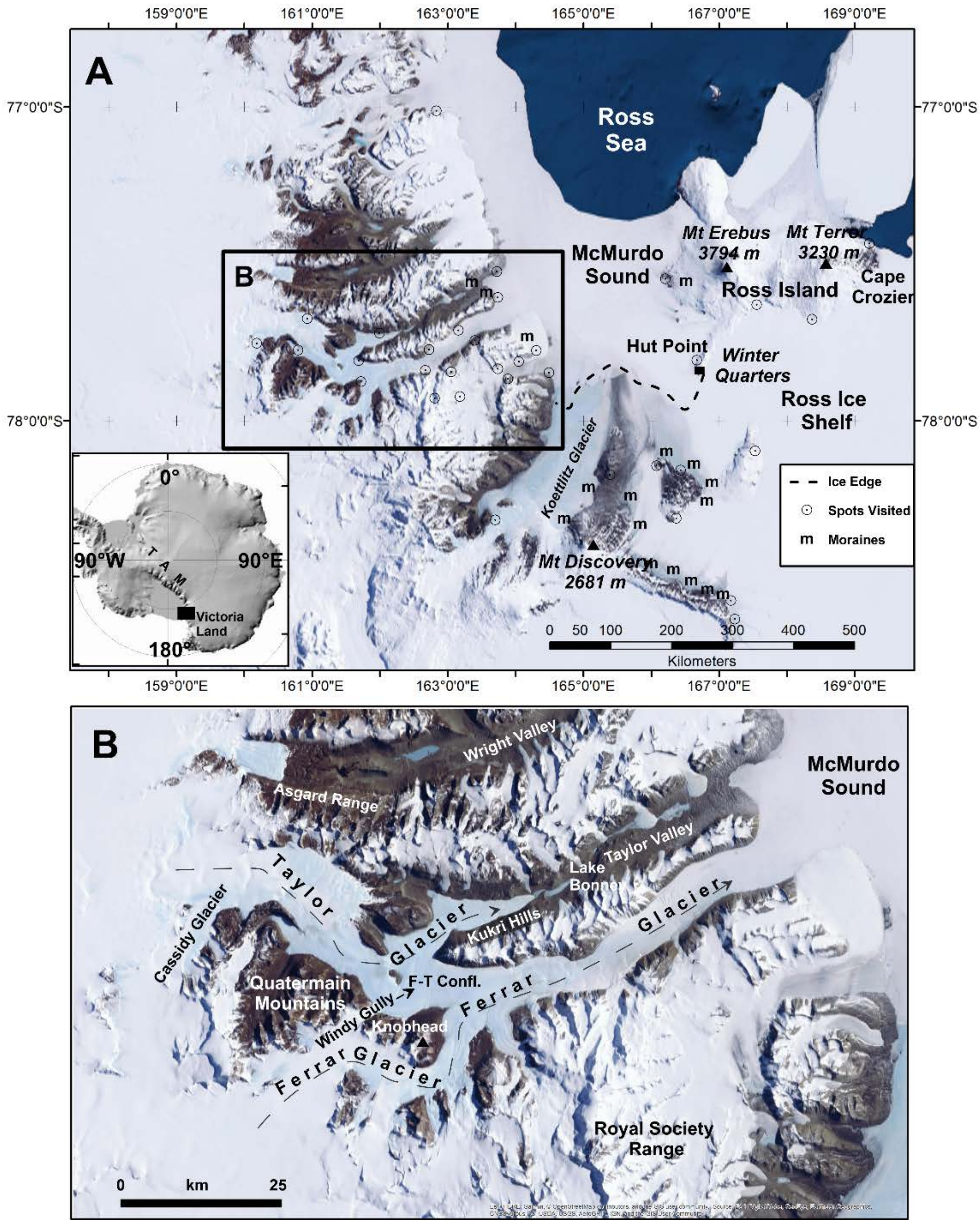


Figure 2: Sites in Antarctica where Ferrar mainly worked. (A) Locations of 'Spots Visited' and moraines, as described on Ferrar's (1905a) map. The position of Hut Point on Ross Island is also shown and the Transantarctic Mountains (TAM) are shown on the inset map. (B) Locations of the Ferrar and Taylor Glaciers, and their confluence (F-T-confl.) in relation to the Kukri Hills and Quatermain Mountains, and the Dry Valleys, Taylor Valley and Wright Valley (Victoria Valley is further north).

Glacier to the northern arm of the Ferrar Glacier (Figure 2), which Taylor had determined was a separate glacier. Scott later confirmed the name of the glacier in Taylor's honor (Sanderson 1988). This seems to have rankled with Ferrar, who wrote to Taylor on 27 September 1913:

> The other day I saw a proof of your map which I understand is to be published in the narrative of Scott's Second Antarctic Expedition. You have omitted the names North Fork

> and East Fork which have appeared on Admiralty charts and displaced the name Ferrar with your own. As your action is contrary to the customs of geographic practice, besides being somewhat in bad taste, I venture to draw your attention to it before the map is finally published . . . (Sanderson 1988, p. 48–49).

Nevertheless, despite Ferrar's letter, the Taylor name was adopted by the Admiralty, and the northern arm of the Taylor-Ferrar Glacier system and valley are named after Taylor (Figures 2 and 3). Ferrar also found remains of Mesozoic plants, indicating that the paleoclimate had been warmer in the past, and explored the volcanic cones of Mount Brewster and Mount Melbourne along the Ross Sea coast and Mount Morning, 70 kilometers south of Ferrar Glacier. Ferrar also monitored volcanic activity on Mount Erebus and Mount Terror (Figure 2B).

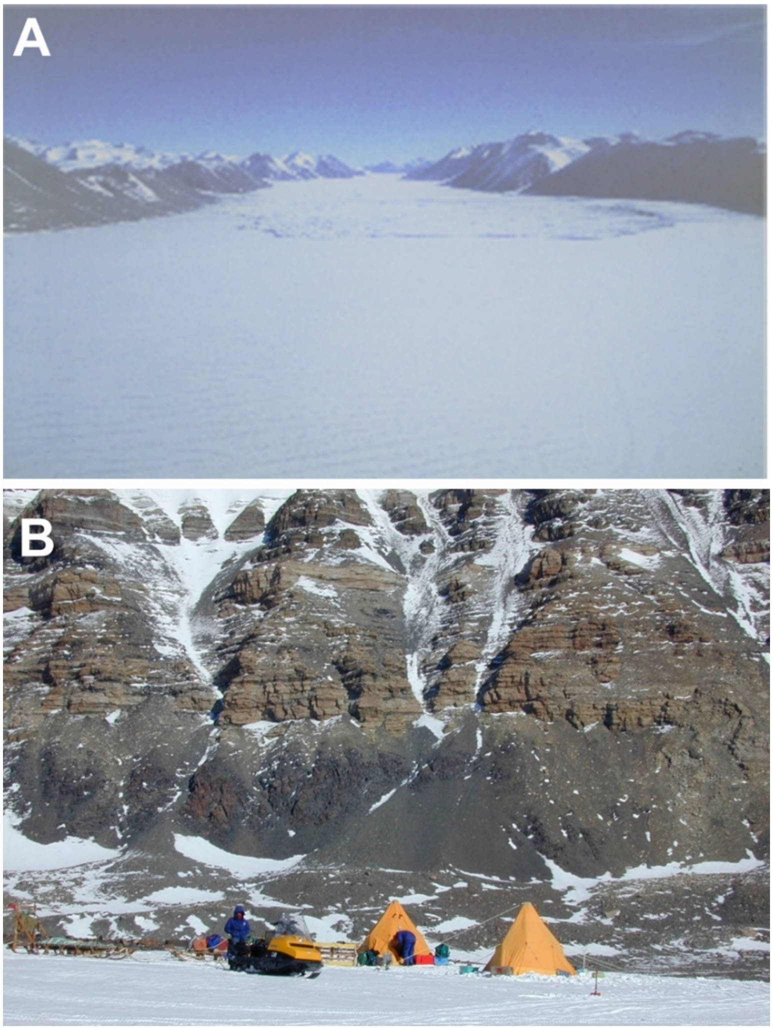


Figure 3. (A) Ferrar Glacier flowing into McMurdo Sound. (B) Beacon Supergroup sandstones, with Ferrar Dolerite intrusion along the base of the cliff (Northern Victoria Land).

On Ferrar's return from Antarctica in 1904, he received the Polar Medal with 1901–1904 clasp and a silver medal for Antarctic discovery from the Royal Geographical Society. He was elected a Fellow of the Geological Society and of the Cambridge Philosophical Society, and obtained his Master of Arts degree. Ferrar then proceeded to publish several significant papers on his Antarctic research, including a review of his observations on the physical geography (Ferrar 1905a). This work included some fascinating photos of glaciers, moraines and bedrock, including dykes and sills, as well as sandstones (Ferrar proposed they be named 'Beacon Sandstone', Figure 3). Ferrar (1905a, p. 375–376) outlined how the Transantarctic Mountains had been dissected by denudation and faulted. He also described a thin carbonaceous layer within the Beacon Sandstone, the first indication of the existence of coal-bearing rocks in Antarctica (Rose and McElroy 1987). One of the many rock samples from this layer which was returned to the National History Museum in London was split open by Dr W. N. Edwards in 1928, and found to contain two fossilized leaves of *Glossopteris indica* (Edwards 1928). This was a significant find, and relevant to continental drift and plate tectonics. Ferrar (1905b) wrote a short paper comparing the weathering of granite in Antarctica with granite in Corsica and Madagascar, before presenting a paper (Ferrar 1905c) which discussed Antarctic moraines, as well as raising questions about the nature of contemporary glacier retreat in New Zealand, and its relationship to glacier activity in Europe and Patagonia. His intrigue relating to possible global glacier-climate teleconnections was an early insight into what has become a key global change issue (*e.g.* Doughty *et al.* 2015): what is the relationship between glaciers and climate in different parts of the globe?

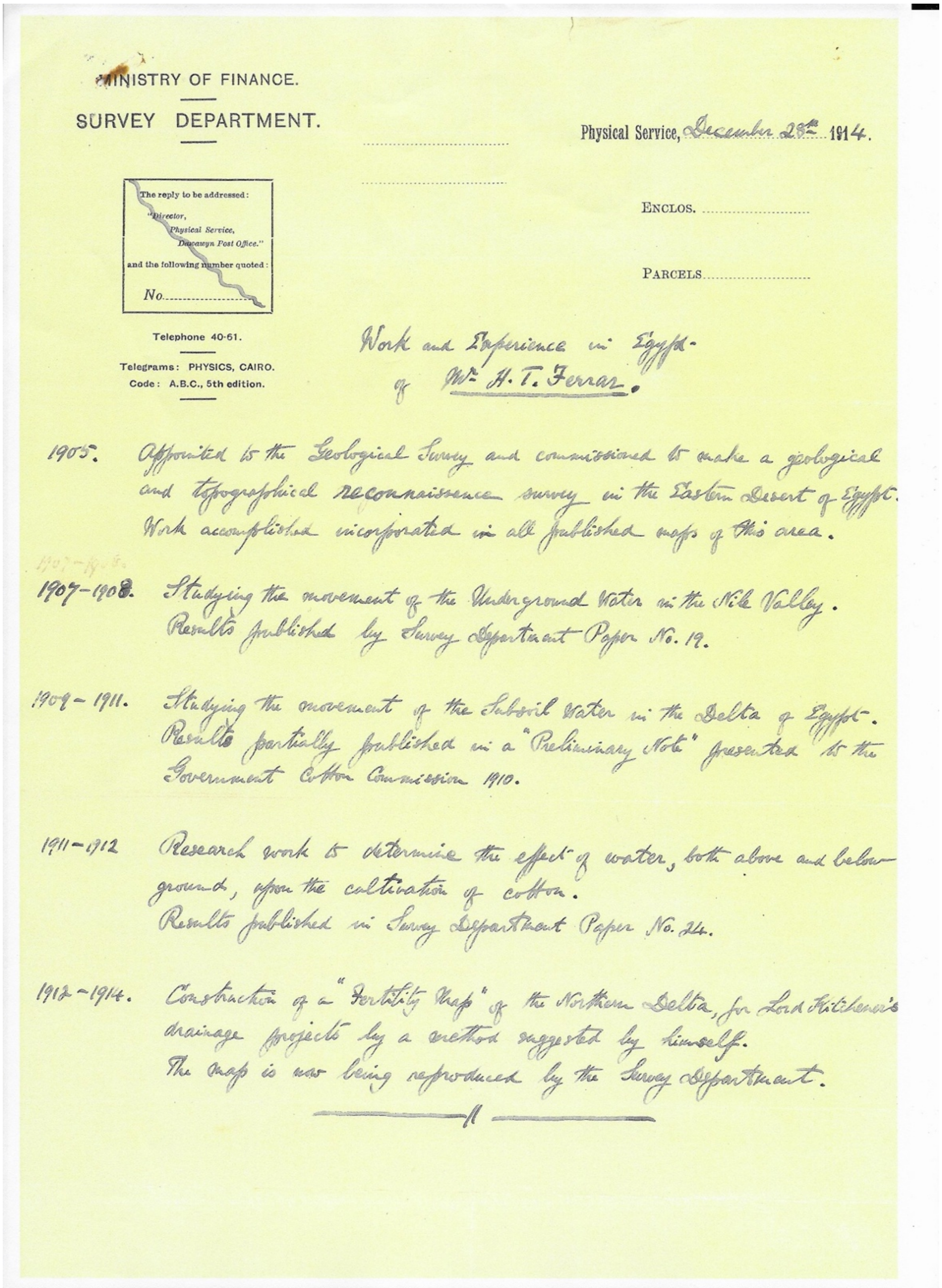
3. FERRAR IN EGYPT

In the autumn of 1905, Ferrar joined the Geological Section of the Egyptian Survey, mapping parts of the Eastern and the Western Deserts. He continued to publish on his Antarctic observations (1905d, 1905e, 1906, 1907a), but was now heavily involved in his work in Egypt (Figure 4). By Christmas 1905 Ferrar had already made a long camel trip into the Eastern Desert beyond Edfu, and by April 1906 he was in the Western Desert (Sellima Oasis) becoming interested in water supply issues (Smith 1932) and publishing his most recent observations (Ferrar 1907b, c, d, e, f).

In late 1907, Ferrar commenced fieldwork in Upper Egypt on the movements of subsoil hydrology, with an emphasis on the effects on cotton and other crops, and this work was extended to Lower Egypt in subsequent years. Results were published in scientific journals (Ferrar 1909a, b; 1910a) as well as Egyptian Geological Survey reports (Ferrar 1910b; 1911). It was during this time that Ferrar undertook empirical field experiments in a similar vein to those he meticulously undertook in Antarctica several years earlier. During 1910–1911, in association with the Department of Agriculture, Ferrar closely monitored the effects of movements of the water table on the cultivation of cotton in the Nile Delta, setting out many lines of tube wells and recording thousands of observations. The experiments proved that there was a steady increase in the crop yield (up to a point) with increases in the thickness of soil above the water table. At this time, Ferrar was also collaborating with the English hydrologist Harold Edwin Hurst (1880–1978) who had started working in Egypt the year after Ferrar. One report they produced together was a study on the effects of water on cotton cultivation (Ferrar and Hurst 1912). Hurst worked until 1968 on Egyptian hydrological issues, and globally became one of the leading hydrogeologists of the twentieth century (Sutcliffe *et al.* 2016).

Ferrar continued to study and monitor the effects of water on cultivation in the Nile area (Ferrar 1913a), but retained an interest in overseas geology. Ferrar had noticed an article published in *Nature* on 25 September 1913 (Reid 1913), regarding a bedrock depression in Dewlish in Dorset. The author, Clement Reid, one of the most prominent geologists of the time, had questioned whether the limestone depression could have formed via aeolian activity under desert conditions during previous cold climates. Two months later, in the 27 November issue of *Nature*, Ferrar (1913b) replied directly to Reid's (1913) paper, making the comparison with his observations of similar features in the Egyptian desert. However, Ferrar (1913b) related that the landform was more likely to be some type of sinkhole, and referred to his own observations of similar landforms exposed in railway cuttings on the London to Cambridge line, as well as in the chalk landscape of the Yorkshire Wolds.

Ferrar (1913b) also remained inquisitive about cognate subjects in Egypt, such as archaeology. Indeed, he made some observations about the Turin Papyrus Mine plan (Ferrar 1913c), a three-thousand year-old ancient Egyptian map, thought to be the earliest map to include



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Work and Experience in Egypt-
of Mr. H. T. Ferrar.

1905. Appointed to the Geological Survey and commissioned to make a geological and topographical reconnaissance survey in the Eastern Desert of Egypt. Work accomplished incorporated in all published maps of this area.

1907–1908. Studying the movement of the Underground Water in the Nile Valley. Results published by Survey Department Paper No. 19.

1909–1911. Studying the movement of the Subsoil Water in the Delta of Egypt. Results partially published in a "Preliminary Note" presented to the Government Cotton Commission 1910.

1911–1912 Research work to determine the effect of water, both above and below ground, upon the cultivation of cotton. Results published in Survey Department Paper No. 24.

1912–1914. Construction of a "Fertility Map" of the Northern Delta, for Lord Kitchener's drainage projects by a method suggested by himself. The map is now being reproduced by the Survey Department.

Figure 4. Ferrar's own summary of his work and experience in Egypt from 1905 to 1914, on Egyptian Survey Department note paper (from the Ferrar Family Collection).

information of geological significance (McMahon 1992). Ferrar (1914a) also contributed to the debate surrounding the origin of a 12 kilometers long embankment, the Gisr El Tod, close to Abu El Matamir. Ferrar (1914a) discussed and rejected the possibility that it could have been of geomorphological or geological origin, concluding that the embankment marked some ancient earthwork fortification, a hypothesis that has been accepted by subsequent historians (Abdel-Fattah 2000).

Coming to the end of his time at the Survey Department of Egypt before returning to New Zealand, Ferrar published four further articles in Volume 8 of the *Cairo Scientific Journal* (Ferrar 1914b, c, d, e). These marked an eclectic mix of interests, and in addition to his longstanding work on irrigation, included a paper on the geology of Antarctica (Ferrar 1914c), as well as a substantial review of Gregory's (1913) *Nature and Origin of Fjords* (Ferrar 1914d). Gregory's (1913) idea that fjords were the result of recent tectonic activity and not glaciation, was soon criticized by others (*e.g*. Johnson 1915). Ferrar's final published work from his years in Egypt included some observations on Permo-Carboniferous breccia (Ferrar 1914f), and loess deposits he had encountered in the Egyptian desert (Ferrar 1914g), as well as a final report on cotton cultivation (Ferrar 1914h).

4. NEW ZEALAND AND PALESTINE

After almost a decade in Egypt, Ferrar returned to New Zealand in 1914 at the outbreak of the First World War, with his wife and their three young children (Evelyn, Helen and Nicholas) and he became a master at Christ's College, Christchurch. He applied his knowledge of cultivation and soil productivity to agriculture in the South Island (Ferrar 1915a, b; 1916), but soon returned to the Middle East with the New Zealand Expeditionary Force, serving overseas from November 1917 to September 1919 (Archives New Zealand, 2010). Ferrar served with the 1st Canterbury (Regiment) chiefly in Palestine, working mainly on interpreting aerial photographic surveys used for intelligence gathering and mapping of Turkish territory (Smith 1932, 1933).

On his discharge from the Expeditionary Force in October 1919, Ferrar joined the staff of the New Zealand Geological Survey, and for the next six years led the mapping surveys in the Northland region (Figure 5). Ferrar's youngest son, Michael, was born in Whangarei in 1921. From a geological standpoint, this was the start (Ferrar 1920a) of an extremely productive and successful period for Ferrar. He undertook work on prospects for coal (Ferrar 1920b) and oil (Ferrar 1920c), including analysis of an oil-shale prospect at Mangonui (Ferrar 1921). Much of this work was undertaken with W. H. Cropp (Ferrar and Cropp 1921, 1922a, b), and included examination of a cinnabar (a mercury sulphide) prospect in the Puhipuhi area, 25 kilometers north of Whangarei. A key question that they examined was the extent of any coal measures (which potentially could contain workable seams). To determine the answer to this question, accurate delineation of the stratigraphic succession in Northland was imperative. Ferrar determined that the coal seams at Tangawahine were vertical and were unworkable. He also had success in that he accurately identified that the coal measures were younger than the 'hydraulic' Mahurangi Limestone which he placed in the Onerahi Formation, but slightly older than the Whangarei Limestone. This diverged from the prior work of James Hector and Alexander McKay, and finally settled the long controversy about the relative age of the two limestones. This is an area of very complex geology now known as the Northland Allochthon, a series of thrust sheets and breccia (mélange). It was known formerly as Onerahi Chaos Breccia, which included Ferrar's Onerahi (and other) formations.

Given the terrain and access, the geological mapping proceeded expeditiously, with Ferrar and his team mapping in detail 1400 square kilometers in the Dargaville district (Figure 5) in the twelve months up to May 1922 (Morgan 1922). Ferrar (1922a) provided his own report on the progress of the geological surveys in Northland, in addition to the annual reports of the Director of New Zealand Geological Survey. Ferrar was also working on soil productivity in the Northland region (Ferrar 1922b), and his careful mapping identified how soil type was related to the underlying parent rock, from which they were derived. His efforts in Northland and the northern Auckland area were reported as the knowledge was accumulated (*e.g.* Ferrar 1923a, 1924, 1925a), and culminated in two substantial bulletins and maps, the 134-page (plus maps) *Geology of the Whangarei-Bay of Islands Subdivision* (Ferrar 1925b) and the 86-page (plus maps) *Geology of the*

Figure 5. Some key locations in New Zealand where Ferrar worked in relation to the major cities.

Dargaville-Rodney Subdivision (Ferrar 1934). The latter was published posthumously, and both reports provided a platform for subsequent work over the next half century. They remain relevant today, and are still cited by researchers, according to Web of Science.

Despite this focus on the mapping of Northland's geology, Ferrar's geological interests remained varied during his time in Northland, and he also reported on some bathymetric work around the New Zealand coastline (Ferrar 1925c). He revisited his observations made in Antarctica two decades earlier, publishing papers on aspects of the geological history of the Ross Dependency (Ferrar 1923c, 1925d), as well as reporting some aspects of the geology of Mangakahia, Coromandel (Ferrar 1926a). Under Ferrar's direction, the geology and topography of 3,400 square miles of terrain in Northland had been mapped in six years.

5. CENTRAL OTAGO

Ferrar's Northland work finished at the beginning of 1926 when he was transferred south to work in Central Otago (Figure 5), and for the following three years, his focus was very much on this area. His knowledge and experience gained in Egypt working on soils and irrigation proved useful, particularly in determining how irrigation could be utilized. Ferrar also helped introduce and apply a more systematic classification and description of soils, based partly on methods introduced in the United States by the US Soil Bureau. This provided an accurate and scientific approach, rather than simple descriptions, and segregated soils types into series, classes and provinces. Consideration was also given to the material lithology and soil profile development (Ferrar 1926b; 1927a, b, c; 1928a, b), but Ferrar (1926b) maintained that using a topographic base map and incorporating climate data was of fundamental importance when soil mapping, as it provided a basic indication of irrigation requirements. With his team of three assistants, Ferrar (1926b, p. 8) reported that soil mapping had proceeded at an average rate of 1000 acres (405 hectares) per day. Ferrar's productivity did not go unnoticed, and in his annual report the following year, the Director of the Geological Survey, P. G. Morgan, commented that Ferrar and his team had completed 1400 square kilometers of soil surveys, but additionally undertook 2200 square kilometers of geological mapping in 'moderate detail' (Morgan 1927, p. 14). Morgan also commented that:

> Much of the geological work undertaken by Mr. Ferrar . . . in great measure it was done by working 'overtime'. (Morgan 1927, p.15).

Ferrar's central Otago work continued, and he provided a succinct description and justification of how and why he had applied the US Soil Bureau's soil mapping techniques in Central Otago (Ferrar 1928c, p. 142), outlining the five soil series and eight soil types present in the 'Otago Soil Province'.

In addition to the compilation of soils maps in Otago, Ferrar was also collecting samples of soil and water for laboratory analyses in Wellington. This was to determine the nutrient content as well as substances that were harmful to plant growth, and he stated that he was collecting a sequence of baseline data to be used as a platform to detect changes in soil chemistry over time, especially due to the impact of irrigation (Ferrar 1926b, p. 9). In particular, Ferrar had already identified that in some parts of Central Otago, soluble sulphates inhibited the growth of pasture grasses. The Otago soil surveys of Ferrar and his team were ultimately written up as *New Zealand Geological Survey Bulletin 33* (Ferrar 1929).

Although focusing on Otago soils for three years, Ferrar also involved himself in other work in the area and beyond. He wrote a four-page summary of petroleum exploration in Egypt (Ferrar 1926c). Closer to home, on behalf of the Public Works Department, Ferrar also made visits to a proposed tunnel at Pegleg Gully and a proposed dam site at Manuherikia Falls in Otago (Ferrar 1926d). The irrigation tunnel was to be driven through a ridge, and he gave advice on (1) slope stability above the proposed tunnel portal, as well as on (2) engineering support methods for the excavation. He gave further engineering geological advice on the faults and joints in the rock on which the Manuherikia Falls Dam was to be constructed (Figure 5). The Manuherikia River and its associated Falls Dam have since then helped sustain primary production in Central Otago for more than 80 years.

Ferrar (1928d) also wrote a paper on the geology of Kapiti Island, providing evidence for recent faulting and uplift. He also published a paper on 'birds of the Ross Dependency', this included a report on the distribution of Adélie penguins, which was considered a valuable contribution several decades later by Taylor (1964). Ferrar investigated evidence for Pleistocene glaciation of Central Otago (Ferrar 1928f), and disagreed with Park's (1909) idea of an early Pleistocene ice cap covering the whole of Central Otago and spreading out to the east coast.

However, Ferrar concluded that Pleistocene valley glaciers extended along the Clutha River valley as far as Clyde and Alexandra (Figure 5), and that there was clear evidence for different glacier advances. McKellar (1960) generally agreed with Ferrar's (1928f) work, while refining it, and commented that Ferrar's work was a 'valuable account' and 'included a long and useful bibliography' (McKellar 1960, p. 435).

Ferrar's final work in the South Island was regarding the magnitude 7.8 Murchison Earthquake of 17 June 1929 (Ferrar and Grange 1929). Ferrar made three key observations. First, abundant earthquake-induced slope failures had occurred, killing fourteen people and destroying homesteads. Second, large displacements had occurred on some faults, including fourteen feet of vertical displacement near the Buller River on the east-dipping White Creek Fault. Third, an area of seabed 55 meters by 1200 meters had been uplifted on the West Coast at Whitecliffs, generally accepted as being the rising toe of a rotational landslide. In addition, landslide-dammed rivers posed a danger of flooding. These observations provide an interesting comparison with the contemporary effects observed from the 2016 Kaikoura Earthquake (*e.g.* Berryman *et al.* 2018), and many earthquakes between these dates.

6. KING COUNTRY AND DEATH

After three summer field seasons in Otago, Ferrar moved north to work on soil surveys in the King Country (Figure 5) for the next four field seasons until his death. In parts of the King Country, nutrient losses in soils were making sheep farming unprofitable (Henderson 1932). Ferrar and Taylor (1929) provided an initial report, with Ferrar (1930, p. 71) pointedly remarking how useful the aerial photographs were, by increasing the 'mapping rate', as well as providing a resource for future use. Ferrar (1931a) provided a second update on soil and geological mapping progress in the Te Kuiti area. Ferrar described the prevalence of a thin covering of recent pumiceous ash (Taupo pumice), as well as resources. These included rhyolitic tuff for quarrying and a coal seam workable at Tahaia.

Ferrar's final work included extending the context and significance of his earlier report on the Murchison Earthquake by providing comparisons between New Zealand and American earthquakes (Ferrar 1931b), as well as providing a report in *Geological Magazine* (Ferrar 1931c). He contributed a final piece of work on Antarctica (Ferrar 1931d), reviewing the meteorology data reported by the British Antarctic Expedition (1907–1909), and on 26 June 1931 was co-opted onto the New Zealand Polar Year Committee. By this time, Ferrar was the Acting Director of the New Zealand Geological Survey, and in February 1932 was awarded a DSc by the University of New Zealand (Fussell 1932). Dr Ferrar died suddenly in Wellington on 19 April 1932 following an operation, having just completed his King Country fieldwork less than two weeks earlier. Ferrar Peak, at 2225 meters in the south-west of Cloudy Peak Range (43°28'10.52"S, 170°47'11.98"E), was named in his honor by B. A. Barrer, one of two climbers who had ascended the (then) unnamed peak in 1931. The name was officially adopted in 1945 (Beckett 1978). Ferrar's passing was noted at the time with obituaries in *Nature* (Smith 1932), *Proceedings of the Geological Society of London* (Smith 1933), the *New Zealand Journal of Science and Technology* (Henderson 1932) and the Victoria University's Student Magazine (Fussell 1932). His geological legacy on different continents is significant.

7. CONCLUSIONS AND LEGACY

Ferrar observed moraines at different altitudes and recognized that the outlet glaciers in Antarctica must have been much larger, under a warmer, wetter climate in the past. He considered the possibility of global climate teleconnections and possible relationships between glacier fluctuations in Antarctica, New Zealand and Patagonia. Ferrar travelled to the Upper Taylor Glacier, and found coal deposits at an altitude of 2,400 meters above sea level. He characterized a broad layer of sandstone found in the region, and this became known as the Beacon Supergroup. Over fifty years after Ferrar's observations in Antarctica, Harrington (1958) named the dolerites that form the well-exposed cliffs along the length of the Transantarctic Mountains in Ferrar's honor. The Ferrar Dolerite is one of the most prominent rocks of East Antarctica, exposed on a vast scale for an igneous rock. Together with its contemporaneous extrusive counterpart in Antarctica (the Kirkpatrick Basalt) and coeval lithologies of Australia (the Tasmanian and Victoria dolerites), South Africa (the Karoo dolerites and basalts) and the Kirwans Dolerite of Reefton, New Zealand, they represent the Ferrar Magmatic Province (Mortimer *et al.* 1995). In pre-Gondwana break-up reconstructions, the Ferrar rocks extended 4000 kilometers in the early to mid-Jurassic, and one of the largest extrusive events, contemporaneous at *circa* 177 Ma (Elliott and Fleming 2002).

In Egypt, Ferrar had carried out the first surveys of the western desert, and his hydrogeological work on irrigation techniques provided a basis for work over the next decades by luminaries such as Hurst. In New Zealand, Ferrar's geological and soil mapping legacy is vast. It varied with the prevailing industrial demands made on the Geological Survey, which evolved from geological mapping for resource delineation, to undertaking soil surveys for the benefit of agriculture. He undertook detailed, systematic geological mapping in several provinces, and his work on soil types and chemistry provided a basis for pasture management. He was instrumental in embracing technological developments and introducing emerging techniques and methods from overseas when he thought they would be useful. His varied career illustrates the different demands that are often placed on a geoscientist, but that careful application of geological principles and diligent work will reap rewards. His final role as Acting Director of the New Zealand Geological Survey, his myriad of publications, in particular the New Zealand Geological Survey Bulletins, provide testament to Ferrar's central role in twentieth century Antarctic and New Zealand geoscience.

Finally, Ferrar's geological legacy is ongoing. His mapping work in Antarctica and New Zealand provides workers with a useful backdrop to the geology of these areas. His work is still cited frequently in the international journal literature as well as regional geological guide books. Indeed, Ferrar's (1907a) field report on the geology of the Dry Valleys area is used and referred to by researchers working in that area of the Transantarctic Mountains, a recent example being Mahaney *et al.* (2018). Ferrar's work in New Zealand is also regularly cited by authors working on aspects of tectonics and volcanism in Northland. For example, Whattam *et al.* (2006) working on the ophiolite complex in northern New Zealand used Ferrar's (1925b) report to define the altitudinal distribution of the ophiolite. Bach *et al.* (2012) also cited Ferrar's (1925b) work on garnet distribution in their analytical study of garnets in the Northland volcanic arc. The current 1:250,000 scale regional geological guide and map of the Whangarei region (Edbrooke and Brook, 2009) refers to both Ferrar's (1925b) report as well as Ferrar's (1934) *New Zealand Geological Survey Bulletin*. Likewise, Ferrar's work in central Otago is still cited by geologists working in the region. In particular, Youngson *et al*. (1998) used Ferrar's (1927b) detailed lithological descriptions when interpreting and redefining the late Miocene-Pleistocene terrestrial stratigraphy of the area. More recently, Craw and Waters (2018) cited Ferrar's (1928d) work to help confirm the approximate Pleistocene glacial limits of central Otago.

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