Discussion

The mechanical and accelerated electrochemical corrosion tests indicated that the higher Cr – lower Ni alloys had very similar properties to those of the AISI fully austenitic Type 316 alloys. Corrosion resistance in dilute sulphuric acid, strength and impact toughness were in fact marginally higher for the experimental higher Cr – lower Ni alloys. The ferrite present in the form of isolated grains in the experimental alloys is not expected to affect the corrosion resistance adversely. Localised depletion of the austenitic matrix of Cr and Mo, and subsequent possible loss of corrosion resistance by such isolated grains is not expected to be significant, an hypothesis confirmed by the electrochemical pitting corrosion tests.

The main undesirable effects of delta ferrite in austenitic stainless steels are related to difficulties during hot working in the steelmaking process,[3] but only at relatively high levels of this phase. This aspect would have to be investigated in greater detail before considering commercial production of higher Cr – lower Ni austenitic stainless steels. The delta ferrite can also undergo an undesirable transformation to the brittle sigma phase after prolonged exposure in the 600 – 850°C temperature range. However, this form of embrittlement usually is not serious in stainless steels containing less than 10% ferrite[4] and thus would not appear to be a major drawback for the experimental alloys investigated.

The FMB type higher Cr – lower Ni British alloys have been reported to possess excellent weldability and also good formability and drawability. Considering the results of the present and earlier investigations, it is conceivable that the higher Cr – lower Ni austenitic stainless steels could possibly offer a viable alternative to the corresponding AISI grades in times where high nickel prices prevail.

Summary and conclusions

Experimental alloys equivalent to the AISI Type 316, 321 and 347 stainless steels but with higher chromium and lower nickel contents possessed very similar corrosion resistance to the AISI alloys in sulphuric acid and chloride containing solutions.

The impact toughness, strength and ductility of these higher Cr – lower Ni alloys also compared very favourably with those of the AISI austenitic grades.

Although the higher Cr – lower Ni stainless alloys are expected to possess excellent weldability and formability, their hot working characteristics in the steelmaking process should be investigated before commercial exploitation is considered.

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History of the Solar Radiation Expedition to Mount Brukkaros, South West Africa, 1926-1931

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The Smithsonian Institution, with financial aid from the National Geographic Society, maintained an observatory on Mount Brukkaros, South West Africa (Namibia), from October 1926 to December 1931 to make daily measurements of the solar constant. The events that led to the establishment of this solar station, its planning and construction, the work carried out there, and the natural history collections assembled by the wives of the observers are described. The reasons for abandoning the observatory and the significance of its results are also discussed.

Die Smithsonian Institution, met finansiële hulp van die National Geographic Society, het van Oktober 1926 to Desember 1931 'n waarnemingstsie op Brukkarosberg, Suidwes-Afrika, onderhou om daagliks die sonkonstante te meet. Die gebeure wat tot die vestiging van hierdie sonwaarnemingstasie gelei het, die beplanning en konstruksie daarvan, die werk wat daar verrig is en die natuurhistoriese versamelings deur die vroue van die waarnemers word beskryf. Die redes vir die sluiting van die waarnemingstasie en die waarde van die resultate word ook bespreek.

In 1926, the National Geographic Society, in cooperation with the Smithsonian Institution, financed a solar radiation expedition to South West Africa (Namibia). No complete account of this event has ever been published. The search for a suitable location for the solar observatory, ending in the choice of Brukkaros mountain, was described at the time by Abbot,[1,2] and recently from a historical perspective by Jarrett.[3] In addition, the wife of one of the observers at Brukkaros published a delightful description of life on the mountain,[4] but this contains few scientific details. Further information about the expedition may be gleaned from the *Annual Reports* of the Smithsonian Institution,[5] the *Annals* of its Astrophysical Observatory,[6–8] accounts of its field work,[9,10] and other published sources. However, the primary source of information for a detailed study of the expedition would be the extensive documentation preserved in the Smithsonian Institution Archives.[11] Additional documents that reflect particularly local involvement in establishing the solar observatory reside in the National Archives of South West Africa.[12,13]

The purpose of this article is to present an overview of the history of the expedition, including the circumstances surrounding its origin, and to consider the significance of its results.

Solar radiation work at the Astrophysical Observatory

The Astrophysical Observatory of the Smithsonian Institution in Washington was founded by Samual P. Langley, who was its director until his death in 1906.[14] Langley believed that careful study of variations in the sun's enery output might enable one to forecast the weather and/or climate some time in advance, and he began regular measurements for this purpose in 1902. Five years later, astrophysicist Charles G. Abbot, who had joined the observatory in 1895, was appointed its director, a post he retain-

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ed until 1944.[14] During these 37 years the observatory was dedicated mainly to the study of possible variations in the solar constant (the solar energy available outside the earth's atmosphere at mean solar distance), and the effect of such variations on the weather. Both short-term (day to day) and longer term (year to year) variations were found, their reality supported by the fact that the former seemed to be associated with the presence of sunspots, and some of the latter with the eleven-year sunspot cycle.

To establish the solar nature of these variations beyond doubt, atmospheric losses, particularly those due to varying amounts of moisture, had to be precisely compensated for. This work required several solar observatories (so that the results might be correlated), situated on desert mountain tops (to reduce atmospheric absorption), preferably distributed over the globe (so that atmospheric conditions at the observatories would not be correlated), and situated at fairly low latitudes (so that the sun would be fairly high in the sky even in winter). Following this reasoning, observatories were established on Mount Montezuma, Chile, and on Mount Harqua Hala, Arizona, in 1920. The latter was moved to Table Mountain, California, in 1925.[6]

As observation sites, instruments and methods improved, the observed variations in the solar constant gradually declined, remaining only just larger than the presumed errors of measurement. As a result, many meteorologists were not convinced that they could be ascribed to the sun.[15] Yet by 1930 Abbot's confidence in their reality led him to predict changes in the solar constant for up to two years in advance. Rewarded by moderate success, he searched for similar variations in temperature and rainfall records, including a series of meteorological observations made in Cape Town (ref. 6, p. 10). Earlier in his *Annual Report* for 1930,[5] he reviewed the evidence to date, concluding that short-period solar variations held promise for weather forecasts nearly a week in advance. With such a prize in sight it seemed important to continue the work.

By 1925, a strong need was felt for observations outside the Americas, to confirm (or correct) those made in Chile and California. As the Smithsonian Institution did not have the funds to establish and maintain a third solar observatory, Abbot approached the National Geographic Society in Washington for financial support. In March 1925 the Society made a grant to him of 55 000 dollars, for the following purposes[16]:

> '1. To select the best location in the Eastern hemisphere for a solar radiation station to cooperate with the two now operated by the Astrophysical Observatory for the measurement of solar variation.
> 2. To equip the station selected.
> 3. To send an expedition to be known as the National Geographic Society Solar-Radiation Expedition Cooperating with the Smithsonian Institution to continue solar-radiation observations as long as the grant permits, estimated at four years.'

The choice of Mount Brukkaros

On the basis of published meteorological data, four countries were chosen for further investigation: Algeria, Egypt and Baluchistan in the northern hemisphere, and South West Africa in the southern hemisphere. Abbot, accompanied by his wife, visited these countries between November 1925 and April 1926.[2] A possible site in Algeria was rejected because of too much cloud. Mount Sinai, then in Egypt, was rejected owing to its relative inaccessibility, lack of meteorological information, and danger from invaders. The best site in Baluchistan, near the Afghan border, was considered too costly and too dangerous.[1,2,6]

Abbot arrived in South Africa around the beginning of March 1926, at the start of four weeks of hectic activity. He approached the South African government (which had administered South West Africa under a mandate since 1920) to ensure official cooperation,[12] which was given in full measure through the Secretary for South West Africa. In Johannesburg he consulted Dr R.T.A. Innes, director of the Transvaal/Union Observatory since 1902, Dr Harold L. Alden, who had set up the Yale Observatory's Southern Station in Johannesburg the previous year,[3] and geologist Dr Ernst Reuning. The last had worked in South West Africa since 1909 and had a detailed knowledge of the country, particularly of the Namib desert. At this time, however, he was investigating platinum deposits in the Transvaal Bushveld,[17] in the company of Hans Merensky.

The region around the town of Aus had been provisionally selected for the observatory,[18] but Reuning recommended the isolated peak of the Spitzkoppe (1728 m), about 80 km west of Usakos.[6] Abbot notified the authorities of his plans to inspect the newly selected region and left Johannesburg on 8 March for Windhoek, the capital of South West Africa.[12] Arriving there three days later, he consulted the Surveyor-General and meteorologists, and decided that Brukkaros mountain, about 100 km north of Keetmanshoop, would be the best site. On 13 March he travelled some 400 km southwards by train to Tses, the small railway station closest to Brukkaros. Here he met Mr A. Dryden, Inspector of Works at Keetmanshoop, who would play a major role in the planning and building of the station. They decided to visit the mountain on 17 March to select a site.[12]

Brukkaros mountain superficially resembles a large extinct volcano. The ring mountain has a maximum height of about 1600 m and a diameter of about 4 km.[19] It is formed of an indistinctly bedded red-brown microbreccia, composed of finely fragmented rocks of the Nama System that were blown out of a volcanic vent about 80 million years ago. The breccia layers slope inwards (unlike the slope around a volcanic crater), and removal of the softer upper layers by erosion has created the central hollow.[20] The hollow is drained by a stream which runs southwards through the ring mountain in a narrow valley. The route into the interior of the mountain is along this valley. At its head is a dry waterfall, over which the stream plunges down some 45 m after rain, and the river bed directly below the fall is the principal source of water.

The morning hours were spent searching for a suitable site on the outer slopes along the eastern side of the mountain,[2] but no suitable rock ledge to build on could be found. Abbot eventually selected a site inside the ring mountain, on the southwestern side. Here the observatory might be somewhat protected against the wind, but was yet supposed to have an unencumbered view eastwards and northwards, as required for observations from sunrise to noon. The choice was made in haste and without proper inspection,[2] and the final decision on the specific site left to whoever would build the observatory. However, the visit convinced Abbot that Brukkaros mountain was an excellent locality for solar work[6]: 'The cloudlessness, isolation, height above all surroundings, official meteorological reports, and other testimony of residents of the neighbourhood all tended to indicate that Mount Brukkaros would prove a good site'. Furthermore, 'these people [the Namas] are peacable, so that no guards would be required' (pp. 72 – 73).

As the mountain was situated in what was then called the Berseba Reservation, permission to build had to be obtained from the local Council, under Chief Johannes C. Goliath (personal communication, Salomon D. Isaacs and David Isaacs, Berseba, December 1988). The Council passed a resolution on 24 March, granting occupation of the site free of charge for a renewable period of four years.[12] Abbot had in the mean time proceeded to Cape Town, from where he left for the United States on 26 March.

The solar observatory

On the day of Abbot's departure he was notified that the Public Works Department was prepared to build the observatory, and was asked to approve the construction drawings. After a delay

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of more than a month because the money that had been cabled from America had gone astray, Mr Dryden was eventually allowed to proceed with the work early in May,[12] which he did with great enthusiasm. During the next few months, he provided Abbot with several progress reports, including photographs.[21] A road was first built from the Nama settlement at Berseba into the foothills of the mountain, for a distance of 15 km. From its end a footpath of about 3 km, which an unencumbered person could traverse in about an hour, was built to provide access to the site.

The design of the solar radiation stations of the Astrophysical Observatory had been standardized in 1919, when E.B. Moore suggested that they should be located in tunnels excavated into the side of a mountain.[6] This design was adopted also for Brukkaros. On the basis of information supplied by Abbot, Dryden had drawn up plans for the tunnel building, on which the concrete instrument piers and even the internal wooden partitions were indicated. This had in fact been done even before they visited the mountain.[22]

Excavation work was started on the site selected by Abbot, but it proved to be unsuitable for tunnelling and Dryden eventually built the station higher up, just below the rim of the mountain. This turned out to be a fortunate change, as the original site would have been unsuitable for early morning and late afternoon observations of the sun druing summer, because of intervening mountains.[23] Even at the new site, no early morning observations were possible during mid-summer.

A shallow tunnel 3 m wide and 2,2 m high was excavated by blasting, and extended outwards by cemented stone walls and a concrete roof to a total length of 10,5 m. This space, divided into three small rooms by wooden partitions and with a stone instrument platform in front of it, formed the solar observatory (see Fig. 1). There was, however, much more to be done. During his visit Abbot had found a shallow cave lower down the slope, which appeared suitable for conversion into a dwelling. But the rock proved to be unstable and eventually a galvanized iron house, lined inside with wood, was erected close to the observatory.[21]

Fig. 1. The Mount Brukkaros solar observatory as it appeared in 1988.

It comprised five rooms and an enclosed verandah. A small stone building was added later to serve as workshop and office.[4] Two water reservoirs of 14 000 litres capacity each were built, one some 140 m below the station to collect surface runoff during the rainy season, and the other next to the house to store water from the roof. A garage for the expedition's truck was built at the foot of the mountain, and a telephone line erected from the railway at Tses. It appears that a telephone was installed in the garage, as a locally hired helper, who later accidentally set fire to the garage, is said to have at least saved the telephone.[4]

Everything was ready for occupation by the end of September 1926. Abbot expressed his satisfaction with the work, stating that Dryden had performed it 'with excellent judgment and assiduity' (ref. 6, p. 73). The building of the observatory and the work to be performed there even rated a description in the South African press a few months later.[24]

Rather surprisingly, the observatory is not indicated on modern topographic maps, although the remains are still clearly visible. Its position is given in various places by Abbot and others as 25°52'S, 17°48'E. However, this is slightly in error, corresponding to the outer slopes on the eastern side of the mountain, where the search for a suitable site was at first concentrated. The altitude of the observatory, which is required to reduce and interpret the results, is also in question. Abbot gives the altitude of the *mountain* as both 5002 feet (1525 m), a value also mentioned by Bleksley,[25] and, more often, 5202 feet (1586 m). The latter height appears also on most maps published before about 1970. When reporting the results obtained at Brukkaros, Abbot wrongly attributed this altitude to the *observatory*.[6] It was subsequently accepted for the South African reduction of the Brukkaros measurements,[26] and is also associated with the meteorological observations made there.[27]

During visits to the site, with the help of a detailed map,[19] pocket altimeter and directional compass, I estimated the station to be at 25°52,8'S, 17°46,7'E, and at an altitude of about 1510 m.

The expedition and its work

The teams manning the solar radiation stations of the Astrophysical Observatory consisted of two persons, a field director and an assistant. The director of the Brukkaros team was Mr William H. Hoover, who was a widower. He was accompanied by his future second wife, Miss Johnson, and his 18-month-old daughter Betty Jean. Hoover was engaged by the Astrophysical Observatory as an assistant in 1923, and trained to direct a proposed Argentinian station. His assistant was Mr Frederick A. Greeley, who had worked at Harqua Hala (1920-1923) and at Montezuma (1923-1926).[6] It was understood that they would remain in South West Africa for three years.[1,4]

The expedition left New York in August 1926, reaching Cape Town on 13 September. Their arrival was noted briefly in the South West African press.[28] They travelled by rail to Keetmanshoop, and had the instruments and household goods transported to the mountain by two oxwaggons.[4] Miss Johnson stayed in Keetmanshoop with Betty Jean until she married Hoover in December, whereafter they too moved to the mountain.

The instruments for Brukkaros were constructed at the Astrophysical Observatory by Andrew Kramer and L.B. Aldrich. (The latter succeeded Abbot as Director.) An Abbot silver-disk pyrheliometer was used on the platform outside the observatory to measure the total flux of solar radiation reaching the ground. A second pyrheliometer was mounted side by side with the first, but not exposed to the sun, for control purposes. The two instruments were equatorially mounted, so that the sun could be followed by adjusting a single screw. Exposures had to be accurately timed, for which purpose a pendulum beating half seconds was used. The altitude of the sun at the time of each pyrheliometer reading was measured with a theodolite, to calculate the amount of air through which the radiation had passed.[7] As a safeguard against instrumental drift, three instruments were maintained at each station, one of which was kept mainly for purposes of standardization.[6] Unfortunately, the pyrheliometers were damaged during the journey to Brukkaros. Although they were repaired at the station, they could not be restandardized and consequently, as discovered later, read about three per cent too high (ref. 6, p. 243).

A pyranometer was used to measure radiation from a circular region of sky around the sun, excluding the sun itself. It was mounted on the same stand as the pyrheliometers, so that it would

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automatically point at the sun with the latter. The observation platform also contained a coelostat, consisting of two flat mirrors, one of which was driven by clockwork and mounted so as to keep the sun's rays reflected continuously through an opening in the northern wall of the building. The mirrors were made of stellite,[1] a hard cobalt alloy containing also tungsten and chrome, which does not tarnish easily. The rest of the instruments were placed in the back of the tunnel for protection and temperature control. Here a well-dispersed solar spectrum was formed, which could be moved slowly over the sensitive strip of a bolometer. As the wavelengths of the visible and infrared spectrum passed over it, the temperature of the strip would change according to the relative amount of energy at each wavelength. The resulting small changes in electrical resistance of the exposed strip, relative to a comparison strip, were measured by means of a Wheatstone bridge and galvanometer, and automatically recorded on a moving photographic plate as a bolograph.[7]

These instruments were used to measure the solar constant in two different ways, referred to as the long and the short method. The long method was fundamental, but could yield only one value of the solar constant per day. It required several bolographs to be taken at different altitudes of the sun, to determine atmospheric absorption at various wavelengths. These results were used to compute the form that the bolograph would have if the atmosphere were perfectly transparent. The area under this computed bolograph (which is proportional to the total energy of the radiation outside the atmosphere) was divided by the area under a bolograph actually observed around noon. The resulting ratio is the factor by which the noon pyrheliometer reading had to be multiplied to obtain the solar constant, after correction for losses in the apparatus, the relative humidity and ozone content of the atmosphere, the unobserved infrared and ultraviolet portions of the spectrum, and the relative distance of the earth from the sun.[6,7]

The short method could produce up to four values of the solar constant per day, but depended for its calibration on the long method. It was developed in 1919 at Calama, Chile, and tested extensively at Brukkaros and other solar stations. It was based on an observed relationship between the intensity of total scattered radiation from an area of sky near the sun, as measured by means of the pyranometer, and the transmission coefficients of the atmosphere across the whole spectrum. After estimating the transmission coefficients at a series of fixed wavelengths, the derivation of the solar constant proceeded as for the long method.[6]

After some preliminary observations during November 1926, daily measurements were started on 9 December.[8] The observations usually occupied the morning from soon after sunrise. The rest of the day was spent in computing the results, which required several hours.[4] The work was continued for the full three-year term with only minor interruptions, mainly as a result of clouds. These breaks were often used to have a picnic on the banks of the nearby Fish river (dry sand except after heavy rain).

In January 1927, Hooever approached the South West African government with an offer to start meteorological observations at Brukkaros and report them to Windhoek, as had been promised by Abbot during his visit. This was gratefully accepted, with a promise that the necessary instruments and instructions would be supplied.[13] After a delay of several months, the instruments arrived early in July,[11] and daily meteorological readings obtained from 11 August 1927 were received by the Weather Bureau in Windhoek.[27]

One of the observers travelled to Keetmanshoop every second week in the expedition's truck, to fetch the mail and supplies. The trip normally took four hours in each direction, but once Greeley could not return for 10 days because the river was in flood.[4] On another occasion, Hoover wrote to Abbot[29]:

> 'I was returning home with a load of provisions and just as I arrived in the middle of the Fish river one of the axles broke. Well, the Fish river is 40 miles from Keetmanshoop and 20 from the mountain. Our native boy was with me, so I sent a note to Fred [Greeley] and he telephoned to Keetmanshoop for an axle. Luckily Hessleman had spare axles and one arrived after a day and a half. In the mean time I camped in the middle of the river. Not a place I would choose for a picnic with the temperature about 100 [degrees Fahrenheit] and a sand storm most of the day'. (pp. 5 – 6)

Life at the isolated station was clearly not easy. Due to lack of rain, Dryden's reservoirs were usually empty,[11] so that household water had to be fetched from the water hole in the valley, and carried up in ten-gallon drums by donkeys.[4] There were several incidents with snakes, and an even more dangerous episode involving a leopard that had stolen some chickens. The animal was eventually caught in a trap, but escaped with the trap attached to its leg. Hoover took the expedition's only firearm, a .22 target rifle, and set off in pursuit. Greeley, armed with a spade, and two local employees (Cornelius Isaacs and Adam Tiboth), armed with clubs, followed him. The leopard was cornered, and killed with two lucky shots.[4]

A slightly more scientific interest in the local fauna is reflected in the following extract from a letter to Abbot[30]:

> 'We have just discovered that we have some of the large lizards [rock leguan] on Mt. Brukkaros. Our native boy killed one a few days ago which was four feet long . . . We shall try to catch one of the large ones and send the skin to you for the Smithsonian [Museum]'. (p. 5)

Hoover also collected specimens of the local rocks and minerals,[11] while his wife developed an interest in the flora of the region. Early in 1929, after good rains had fallen, flowers came up everywhere on the mountain, whereupon she collected and pressed some 50 varieties.[4] After her return to America she donated her collection of 103 specimens to the United States National Museum in Washington.[31]

Replacement of the observing team

On 5 September 1929, at the end of their three-year term, Hoover and Greeley left Brukkaros to return to Washington. Hoover was appointed to the post of Associate Research Assistant, detailed to the Division of Radiation and Organisms, and promoted to senior astrophysicist in 1937. At the time of his unexpected death, on 11 September 1953, he was Chief of the Division of Astrophysical Research.[8] Greeley became assistant at the observatory on Table Mountain, California, and later at Mount Katherine, Egypt. By 1953 he was in charge of the Montezuma observatory in Chili.[8]

The National Geographic Society grant was insufficient for another term of three years, but a staunch supporter of the solar programme, Mr John A. Roebling of Bernardsville, New Jersey, was prepared to carry the cost of continued observations at Brukkaros. Roebling had already made various other grants to the Astrophysical Observatory's solar research programme since 1920, and continued his support until his death in 1952. The new observers were Mr Louis O. Sordahl, a graduate of the University of Wisconsin,[11] who had served as assistant at Table Mountain during 1928-1929. He was accompanied by his wife, and assisted by Mr A.G. Froiland. They arrived at Brukkaros on 3 September 1929, two days before Hoover's party left.

Observations were continued by the second team until November 1931, with only minor interruptions. The most noteworthy of these occurred on the night of 23 January 1930, when the interior of the observation tunnel was struck by lightning during a thunderstorm. The bolometer, resistance box and some wiring were burnt out, but the galvanometer survived intact.[11] Fortunately a second bolometer was available, and Sordahl 'by diligence and clever adaptations, was able to restore the circuits

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so as to recommence observing with the loss of only 4 days'.[32]

Another product of Sordahl's skill with tools and materials was a solar water heater, which proved quite effective. This was clearly far ahead of local custom at the time, as indicated by his remarks to Abbot in his letter of 10 November 1931:

> 'Solar heaters are unheard of in this region and I have repeatedly suggested to some that they should make one rather than buy expensive copper heaters to heat their water as well as they must buy all fuel at tremendous prices, but they all looked at me as though I was "kidding" them into a good joke.'

The post of assistant

Froiland was recalled to Washington before the end of his term, departing on 20 March 1931.[11] However, he remained in the service of the Astrophysical Observatory until at least 1952.[8] Sordahl requested the universities of the Witwatersand, Cape Town and Stellenbosch to recommend suitable candidates for the post of assistant, and received four applications. He appointed Mr (later Professor) Arthur E.H. Bleksley (1908-1984), who arrived a day before Froiland's departure.[11] Bleksley brought a 76 mm object lens with him, which was used with various odds and ends to assemble a telescope for the observatory. However, he wished only temporary employment and departed on 30 August 1931 for a post in Johannesburg. Another of the original applicants, Mr D.J. Hattingh, was then appointed, but he remained only about four weeks. Thereafter Mrs Sordahl took over some of the work.[11]

Mrs Sordahl's natural history collection

Sordahl's wife (whose first name was Margaret,[11] but who is referred to in the literature by her husband's initials) had zoological training and was an active naturalist. She brought the necessary collecting equipment with her and, upon her return to Washington, donated her specimens to the United States National Museum. In the Annual Report of the museum for 1932[33] the collection is described as follows (p. 7):

> 'One of the most interesting general collections of biological material was obtained by Mrs L.O. Sordahl while at the solar observatory of the Smithsonian Institution on Mount Brukkaros in Southwest Africa. This includes birds, mammals, reptiles and plants, some of which are new to science, and many of which had not been represented previously in the National Museum, as the region is one from which we have had little or no material.'

Some additional details are supplied in the report of the Head Curator for the Department of Biology:

Mammals: 'The collection of 49 mammals brought back by Mrs L.O. Sordahl . . . included representatives of five genera new to the Museum' (p. 46).

Birds: 'Mrs L.O. Sordahl's collection of 48 skins, 6 nests, and 3 eggs . . . included 9 forms of which the museum did not previously possess representatives' (p. 47).

Reptiles and batrachians: 'The most important accession . . . was the small but excellent collection made by Mrs L.O. Sordahl in Southwest Africa . . .' (p. 47).

Insects: 'Mrs L.O. Sordahl presented 561 insects collected by her in Southwest Africa' (p. 48).

The Museum's list of accessions[33] credits Mrs Sordahl with '49 mammals, 48 birds, 75 reptiles and amphibians, 661 insects, 7 molluscs, 2 crabs, and 158 plants, all collected in the vicinity of Mount Brukkaros and Keetmanshoop, Southwest Africa' (p. 145). Most of the plants were veld flowers, but 44 varieties of grasses were also collected.[11] During 1933 she donated one further plant from South West Africa,[34] and also acted as go-between for a donation of '10 phyllopods [an order of the crustaceans], collected in 1931 at Omaruru, Southwest Africa' by Dr Zschokke of Keetmanshoop (p. 183). Dr Markus Zschokke, formerly an instructor at the University of Zurich,[11] was veterinary surgeon at Keetmanshoop at the time.

The Sordahl collection of birds was described by Friedmann.[35,36] Of the 24 forms, seven were new to the collections of the U.S. National Museum, and two were considered new to science: Abbot's ground robin (*Erythropygia coryphaeus abboti*; not admitted as a separate race today), collected along the Fish river and 'named in honor of Dr Charles G. Abbot, Secretary of the Smithsonian Institution, at whose suggestion the observatory on Mt. Brukkaros was founded' (ref. 36, p. 65); and *Poliospiza albogularis sordahlae* (now considered a local race of the White-throated seed-eater, *Crithagra albogularis*), collected on Brukkaros mountain and 'named in honor of Mrs L.O. Sordahl who maintained her interest in zoological collecting under rather trying and difficult circumstances' (ref. 36, p. 66).

Brukkaros observatory closes down

The results of the solar measurements were sent to Washington about every three months[11] for further analysis and comparison with the results obtained at the two other observatories. This led to the realization that the Brukkaros pyrheliometer readings were too high, owing to the damage the instruments had suffered on the outward journey. Abbot decided to correct the results by reducing them by the following amounts: December 1926 to 1 November 1927, 2,4%; 1 November to 8 December 1927, 2,9%; and after 8 December 1927, 3,7% (ref. 6, p. 243). The corrected daily values of the solar constant for the period December 1926 to December 1930 were published in Volume 5 of the *Annals of the Astrophysical Observatory* (pp. 190 – 193, 223 – 230).

Even after these corrections, the solar constant values obtained at Brukkaros were less stable than those recorded at Montezuma, and their variations did not always match those found at the latter station. When computing recommended daily and monthly values of the solar constant, the results obtained at Brukkaros were therefore given half the weight of those from Montezuma (ref. 6, p. 278).

The unsatisfactory results were due mainly to meteorological conditions that rendered the compensation for atmospheric absorption inaccurate. Two factors appeared to be mainly responsible for this.[37] First, Brukkaros observatory was at a much lower altitude than those in Chile and California. This caused both more, and more variable atmospheric absorption than at the American observatories, particularly since hazy conditions often prevailed.[11] In fact, Hoover concluded that the short method as developed in the Americas did not take the variable atmospheric conditions at Brukkaros fully into account.[38] Second, the site proved to be more windy than expected, particularly during the winter months. Hoover reported that[39]

> 'During the five months May to September [1927] there are about 25% of the days with strong winds, above 20 or 25 miles an hour. On some of these days it is impossible to observe at any time during the day (about 10 days during the year). On many days the wind is too strong in the morning but [it is] possible to observe in the afternoon. We have had days with wind velocity of 60 miles per hour.'

These strong winds often carried dust over the mountain, affecting the results of both methods of determining the solar constant (ref. 7, p. 83n). Furthermore, the winds were usually gusty rather than steady, affecting the observers and their instruments directly. The galvanometer in particular became unstable, so that good results could not be obtained on windy days.[11]

Besides atmospheric problems, two other factors interfered with the solar constant work. One, already referred to, was the siting of the observatory, which prevented the long method from being used in the morning around the middle of summer. The other was the accumulation of static electric charges inside the tunnel

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on very dry days. This affected the deflection of the galvanometer, and thus the bolographs, causing erratic results on otherwise excellent days.[11] Various remedies were tried, but without much success.

The observatory was closed in December 1931,[40] after both the solar[8] and meteorological[27] observations had been discontinued on 20 November. Rather ironically, a few months later a volcanic eruption in southern Chile caused a haze at Montezuma that interfered seriously with measurements of the solar constant for several months.

The expedition's work was considered important enough to deserve a mention in the Official Year Book of the Union of South Africa,[41] which also reported the station's closure.[42] Ownership of the buildings was transferred to the government of South West Africa 'in view of possible similar use in the future'.[43] Sordahl donated the furniture to Rev. Eberhardt Eisenberg of Berseba, and three donkeys to a local employee, Mr Thomas Higoam.[43] The latter, aged 82, now lives in the nearby settlement of Gainachas, and clearly remembered the names of the observers, as well as the gift of the donkeys, when I visited him in December 1988. The observers left Keetmanshoop on Christmas day 1931 for South Africa, to return to the United States by sea via Egypt.[12] The galvanized iron house was eventually offered for sale in 1940, at which time it was reported to be still in good condition.[12]

Sordahl had been considering other employment while still at Brukkaros,[11] and left the Astrophysical Observatory on 30 June 1932. The instruments were brought to Washington and donated to the Smithsonian Institution by the National Geographic Society. They were subsequently used at a new station on Mount Katherine, Egypt,[7] and in Chili.[8]

The observation tunnel, and the instrument platform in front of it, are still in reasonable condition, although the door and window panes have been removed (Fig. 1). Inside the tunnel three of the original four instrument piers are still in place. About 100 m west of the observatory are the remains of a stone building of some four by seven metres, beyond which lies the floor of the house. The stone building, with its two doors in opposite walls, can be identified from Mrs Hoover's description[4] as the one where they enjoyed their Christmas dinner in 1927, with friends from Keetmanshoop: 'We ate in the new building. It hadn't become the [work]shop and office yet, because the partition wasn't in, so it was one long room of grey cement walls and floor, with a door at each end . . .' (p. 501).

The view has been expressed that the photographic records of Brukkaros observatory may have been sealed up in the tunnel building on the expedition's departure (personal communications, James I. Ebert, Albuquerque, 1986 and 1988). However, I found no indications of this, nor any evidence that the plates had been buried or discarded anywhere near the site.

Although people occasionally visit the mountain, the state of the last section of the footpath and the absence of litter suggest that few visitors venture as far as the old observatory.

Moore's expedition

Abbot's relentless search for sites with better atmospheric conditions is reflected in his lament, written in 1931,[6] that 'nowhere in the world are the atmospheric conditions good enough to fully satisfy the exacting demands of the study of solar variations'. (p. 65).

By June 1930 consideration was given to moving the Brukkaros observatory to a better locality, and Sordahl made some preliminary enquiries about conditions at likely mountain sites. One of the persons he consulted was Dr Zschokke, who visited Brukkaros around September 1930. Zschokke, who had 'travelled over all of lower S.W. Africa in his official capacity,'[44] recommended the Erongo mountains (highest peak 2305 m), just north of Usakos. However, measurements of solar radiation at various sites seemed to be required. Fortunately,

> 'impressed by the probability of useful weather applications, Mr Roebling has made a further grant to finance an expdition of a year's duration in Africa and outlying regions to endeavour to find a site equal to Montezuma, Chile, for solar radiation work. [Mr Alfred F.] Moore, who has had long experience at our mountain observatories, occupied Fogo Island peak in the Cape Verde Islands for several weeks, and is now [about October 1931] in Southwest Africa testing various high mountain sites in comparison with Mount Brukkaros'.[45]

Moore arrived in South West Africa in June 1931[11] and left with the Brukkaros expedition at the end of December.[46] He investigated conditions at the Erongo mountains, but found too much cirrus cloud there. The Brandberg (2614 m), about 100 km to the north-west, was rejected for the same reason, and because he could not get his instruments to the top. To those who know the mountain this will be no surprise. Lord Hill (2202 m), a peak in the Karas mountains some 90 km south-east of Keetmanshoop, and Gamsberg (2347 m), 120 km south-west of Windhoek, were found to be less hazy than Brukkaros, but more cloudy.[46] Gamsberg was judged to be a better site than Brukkaros, but not enough to warrant a permanent station.[37] Moore therefore proceeded to Egypt, and between April and July 1932 found a satisfactory site on Mount Katherine.[40] This site was occupied in March 1933 by Harlan H. Zodtner, assisted by a veteran of Brukkaros, F.A. Greeley.[7]

Evaluation of the Brukkaros results

Several years after the Brukkaros observatory had been closed, when reporting recomputed daily solar constant values for the period 1923 to 1939, Abbot had quite dissociated himself from the Brukkaros results (ref. 7, p. 42n): 'The station at Mount Brukkaros, Southwest Africa, was also occupied during the interval to be covered here, but it was so far inferior that its results have not been reduced, and must be looked for only in Volume 5 of these Annals where they are subject to sources of error which we have now eliminated'. With regard to the future recomputation of results, he thought it possible that the observations made at Harqua Hala (another unsatisfactory station) might be revised, but 'we do not intend to revise the work at Mount Brukkaros' (p. 83). In the long run, therefore, the results from Southern Africa contributed very little to the solar constant work.

However, this does not mean that the observations were worthless, as the inaccuracies entered mainly in the process of compensating for atmospheric absorbtion. The pyrheliometer measurements of the radiative energy that reached the ground were not affected by this, although they may be subject to possible small errors arising from the re-standardization corrections that Abbot applied to them. These measurements were not available in Southern Africa until 1952, when A.J. Drummond, investigating early solar radiation work in South Africa, became aware of their existence at the start of the South African Weather Bureau's country-wide radiation survey. The 3000 pyrheliometer readings, with their associated air mass values, were made available to the Weather Bureau by Dr Aldrich, then Director of the Astrophysical Observatory, and published soon thereafter.[8] As these measurements had been standardized on the 1913 Smithsonian scale, they were reduced to the Ångstrom pyrheliometric scale that had been adopted in South Africa.[26] This involved multiplying them by the best available conversion factor between the scales, namely 0,965. At that time the observations were considered quite useful, as they represented the longest series of measurements of the solar radiation incident on the central plateau of Southern Affrica.[47,48] Following their reduction and analysis, they were used for two purposes: first, to calculate the amount of direct solar radiation available at various times during

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the day and year, for possible industrial applications;[25,49,50] and second, to estimate the amount of total (sun plus sky) radiation for climatological purposes.[26,48] For the latter the Brukkaros measurements were combined with more recent results obtained at Windhoek and other stations.

Although the Brukkaros solar expedition was therefore not very successful in meeting its primary objective, it none the less made a useful contribution to Southern African climatology some twenty years later. Of course, even in this domain its results were soon replaced by a large volume of later and more accurate observations. Yet, as a similar fate befalls most scientific endeavours, this does not detract from the expedition's importance. It deserves to be remembered as a significant event in the history of science in Southern Africa.

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