Meteoritics & Planetary Science 49, Nr 7, 1271–1287 (2014)
doi: 10.1111/maps.12332

Report

Oral histories in meteoritics and planetary science—XXV: Vagn F. Buchwald

Derek W. G. SEARS

NASA Ames Research Center/Bay Area Environmental Research Institute, Space Science and Astrobiology Division, Moffett Field, Mountain View, California 94035, USA
E-mail: derek.sears@nasa.gov

(Received 28 March 2014; revision accepted 15 May 2014)

Abstract–Vagn Buchwald (Fig. 1) was born in Copenhagen where he attended school and college. Then after 18 months of military service, he assumed a position at the Technical University of Copenhagen. A few years later, he was presented with a piece of the Cape York meteorite, which led to an interest in iron meteorites. Through a campaign of informed searching, Vagn found the 20 ton Agpalilik meteorite (part of the Cape York shower) on 31st July 1963 and by September 1967 had arranged its transport to Copenhagen. After sorting and describing the Danish collection, which included application of the Fe-Ni-P phase diagram to iron meteorite mineralogy, Vagn was invited to sort and describe other iron meteorite collections. This led to a 7 yr project to write his monumental *Handbook of Iron Meteorites*. Vagn spent 3 yr in the United States and visited most of the world's museums, the visit to Berlin being especially important since the war had left their iron meteorites in bad condition and without labels. During a further decade or more of iron meteorite research, he documented natural and anthropomorphic alterations experienced by iron meteorites, discovered five new minerals (roaldite, carlsbergite, akaganeite, hibbingite, and arupite); had a mineral (buchwaldite, $NaCaPO_4$) and asteroid (3209 Buchwald 1982 BL1) named after him; and led expeditions to Chile, Namibia, and South Africa in search of iron meteorites and information on them. Vagn then turned his attention to archeological metal artifacts. This work resulted in many papers and culminated in two major books on the subject published in 2005 and 2008, after his retirement in 1998. Vagn Buchwald has received numerous Scandinavian awards and honors, and served as president of the Meteoritical Society in 1981–1982.

DS: Why don't we start by you telling me how you became involved in meteorites?

VB: It started in 1957 when the curator for mineralogy at the Geological Museum, Sole Munck, telephoned me and asked for help. She had received, from northern Greenland, an iron meteorite that had been found on a nunatak near the Moltke glacier in the Thule district. It had been found by an American surveyor who was up there to measure the velocity of glaciers moving before him. He was standing on a nunatak, which is where rocks protrude from the ice. When he put his tripod down he could not escape noticing a rusty stone that turned out to be a meteorite. Since we had an agreement with the Americans that anything of natural interest that was found in Greenland would be delivered to the Geological Museum in Copenhagen it came to Denmark. It was 48 kg and looked like a goose with a body and head and a neck. It was very difficult to cut because it was difficult to mount, it was very irregular, so they had given up in the machine shops of the museum. But I was nearby in the Technical University and I was a metallurgist and I was approached. But I had never cut a meteorite before. It was quite a challenge. I could not do it myself. I had help from some good friends I had in the factories nearby and they helped me with a band

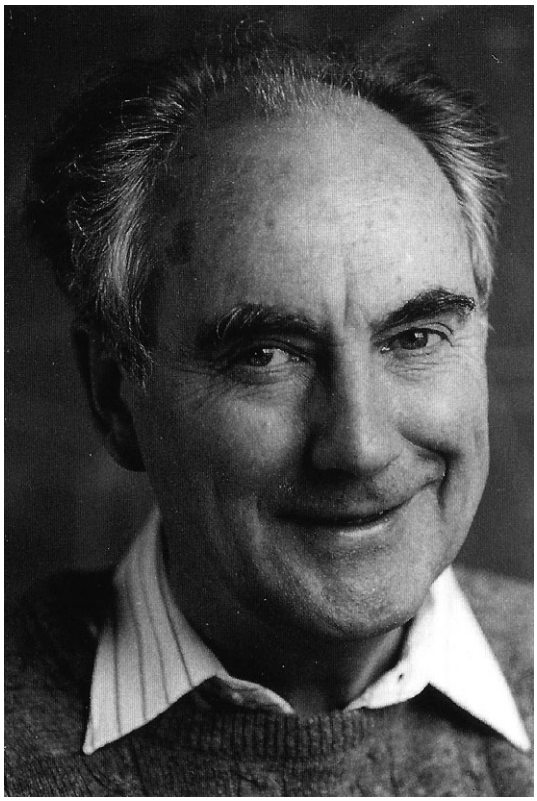

Fig. 1. Vagn F. Buchwald.

saw where the workmen held the meteorite in their hands while the band saw cut the meteorite where we wanted it. We cut it at the base of the goose so that it would stand. The cut went through where you would expect an egg and there was an egg! A big inclusion. It was troilite but I knew nothing about meteorites. We had a professor from Sweden come through and I showed him the meteorite under the microscope and he knew; he was a very bright man, Mats Hillert. He said to me that I should consider a career in meteorites. I was in a department of metallurgy, but I was free to pursue anything else in my research. So I could pursue an interest in meteorites. I was currently involved in research on friction and wear, which was tedious, and I was alone and knew that there were many laboratories pursuing this type of work. Everybody was occupied by friction and wear. All the oil companies were interested in lubrication.

DS: So the subject came to you?

VB: The subject came to me. Basically, I had been interested in stones and rocks since my childhood. I have a picture here where I am 4 yr old looking at a large boulder. I am looking very interested!

DS: A 4 yr old geologist.

VB: Yes, truly. And I started to collect rocks when I was 4 yr old.

DS: That's a good point to turn the clock back and talk about your precollege days. First, tell me about your parents, your early upbringing.

PRECOLLEGE AND COLLEGE YEARS

VB: I was born in Copenhagen in 1929. I lived in Copenhagen on the fifth floor of an apartment building for 25 yr. My father was a professor in botany with a specialty in plant diseases. He worked on coffee plants, potato plants, and fungi that were growing naturally in the forest. He founded a society for studying mushrooms, which were very popular in the dark years of the war. Nobody could move around, there were no cars, but you could take the train into the forests around Copenhagen and pick mushrooms. I was brought up with mushrooms and botany. In April 1940 Denmark was occupied by the Germans and there was no gasoline, windows had to be covered with black paper so the British airplanes could not see us, and we had to stay inside. I played with a little puppet theatre with my friends and built "technical" models with my sets of Meccano. At that time my father was with the Royal Veterinary and Agricultural School which is now part of the university. My mother was a nurse, but gave it up when we were small. I have a younger brother with whom I shared a room. We had bunk beds.

During the war, the British were asked to help Denmark destroy the Gestapo headquarters in Copenhagen. That is a story in itself. The British used Mustangs and Mosquitos flying low from Britain over the North Sea and over Denmark at a height of 30–40 m so they could not be detected by German radar. It was March 21st, 1945. The German Gestapo Headquarters were very near the Town Hall in Copenhagen and one of the planes lost control and was trying to find somewhere to land without hurting anyone. It landed in a garage a few meters away from two schools. At the time I was standing near a window with a piece of clay in my hands. The teacher had asked me to explain to the students what the Danish subsurface was like. So I had this piece of Danish clay in my hands when the plane dropped on the garage opposite. There was an explosion, lots of fire, and part of the other school caught fire and about 160 people—children and teachers—were killed. We were rushed to the basement, to the shelter, and when it was all over we went out to help. As boy scouts, we had been taught to clear the area around a fire to prevent it spreading but we had not realized that a four or five story building burning produces so much heat that you can't stay there. A Danish Nazi came with a gun, pointed it at my side, and said get

out of here. Go back to your mother. Let it burn. I was going on 16 at the time.

DS: So your formative years were dominated by the war. Do you remember the liberation?

VB: I had a camera and I got a close-up of Montgomery. I still have the picture. I remember talking to the British sailors whose ships were anchored in Copenhagen harbor. They would be standing around, lighting up cigarettes, and giving packs away. I did not smoke, however.

DS: You said your father was a professor. What sort of man was he personally?

VB: Everybody loved him. He had many friends.

DS: Did he spend a lot of time with you?

VB: Yes, he helped me with my stamp collection and on my seventh birthday he bought a huge catalog for stamps. It was in German, so I had to learn German, and I did, because I wanted to know about the stamps. He was very supportive. Absolutely. And later on at the university he paid for everything, not that you have to pay much for university in Denmark. It is almost at no cost, you just have to pay living expenses. It is still the case today.

DS: What about your mother? What type of person was she?

VB: She was very sweet, but she could not hold a knife, she was very handicapped. She died much too early, at 62. She had the nurse's job but she gave that up when I was 2 or 3 yr old. She did all the work at home. My father was never seen in the kitchen. My father would come home from the forest with mushrooms and she would prepare them for us to eat and examine whether they were poisonous.

DS: Would you say you got your scientific temperament from your dad?

VB: Yes, and perhaps from my grandfather who worked on the railroad, he was a station master, a gentleman, and a great hunter, with a dog. He introduced the first hunting dogs with short hair, hound dogs. He often judged the dogs at the county fair. During the war I was sent from Copenhagen to him at Langaa wearing a label like a package! He was always on the railways. He started at 18 yr—you had to take an examination—and he retired as station master in Viborg at 68; when he reached mandatory retirement.

DS: Well you have told us about your parents and your early childhood, what about your high school. What subjects did you study?

VB: At 18 we graduated high school. That was after 12 yr in the high school. It was 1947. I was very interested in Danish history; I still am.

DS: Is it possible to say how your adult years were affected by the fact that your teenage years were dominated by the war?

VB: Oh, it was something I could leave behind. What is more important are the friends you have in school. One became a sea captain, and I like to sail. Your friends are very important.

DS: Your CV contains multiple mentions of bicycling throughout your childhood and adult life.

VB: Yes, I love to cycle. My first cycling tour with three friends was in 1949 (Copenhagen-Skåne-Blekinge-Öland-Gotland), then in 1951 we cycled through Germany (Lübeck, Hannover, The Harz, Göttingen, Miltenberg, Heidelberg, Mainz, Maria Laach, and Köln), and in 1952 it was the Alps (Venezia-Verona-The Dolomites-Grossglockner-Salzburg). Kirsti and I still go to the grocery stores on our bicycles.

DS: You also had an exhibition of your rock collection in 1947.

VB: Yes, they had contests for various types of collections. What was sickening is that at the end of the contest my specimens of amber had been stolen!

After the war and after we graduated high school we were encouraged to help people in Finland who had been expelled from the Carelia region by the Russians. With nine other Danes we spent 3 months in 1948 rebuilding the region. I learned Finnish, which is difficult (Finns have an equally difficult time with Danish). We put up about 6 km of barbed wired fence to keep in the cattle. When this was finished we pulled up trees, and cleared the land so people could live on the border with Russia. About 450,000 people were made homeless by the Russians. We lived in an old hut near the border that had been built by timber men. We took food to share. The Russians still have the land. It's about 10% of Finland. I met my wife at that time.

DS: You came back from Finland with a wife?

VB: No, no, that took 9 yr. We met in 1948 and married in 1957. We had many commitments, studies to finish, and so on. It was a long courtship. We visited often, and we wrote.

DS: At this time (September 1948) you started as a student at the Technical University of Copenhagen?

VB: Yes, my main subject was chemistry, inorganic chemistry, and in the last few years I specialized in metallurgy. There was very little metallurgy in Denmark at the time. We were building up a department, there were no textbooks in Danish, just German. It took 4½ yr to get my degree.

DS: Then to the PhD degree?

VB: No, I never got a PhD. It was not possible at that time. They started it a few years after, but too late for me. I got a Doctor of Science degree several years later (October 1977) on the basis of just one publication. It is very different from a PhD.

DS: It's analogous to the British Doctor of Science degree; a degree some universities offer after about 10 yr of an independent career.

VB: The Germans have something similar. The main thing is that it is independent of work done at the university as a student. You are entirely on your own.

DS: You went on your first expedition as a student?

VB: Yes, 1950, that is when I was half way in my studies. I was interested in geology and I had an interest in nature and an interest in Greenland. So with a close friend I turned in a request to the state asking if we could participate in the next expedition to Greenland. Lauge Koch was an eminent expedition leader that took a group every year since 1930 to north Greenland where you mapped that part of Greenland geologically. They stopped during the war but after the war they continued every year. In 1950 my friend Flemming and I applied.

DS: This was a summer activity that did not interfere with your academic studies?

VB: Yes, 3 months, that is right. We found the lead and zinc mines that operated for many years. We were the youngest in the group.

DS: How many participants were in the group?

VB: One hundred twenty. I was appointed to the chief geologist who was Josef Eklund from Sweden. He showed me how to take specimens. I cooked him porridge. At one point we were almost stranded. For 14 days we could not move. But if we walked 70 miles up the coast we would find a station where they caught seals. I killed a musk ox for some food. I had never killed an animal before. Then a storm came and pushed away the ice and we could get out. We could then be air-lifted back to the main camp by sea plane.

DS: That is in the summer of 1950. Before we leave your formal education is there anything else? How did you make the transition from chemistry to metallurgy?

VB: It is not really a transition. Metallurgy was seen as a branch of chemistry. In this country we have no major engineering companies, so metallurgy is considered a branch of chemistry. It is different in Norway, Finland, and Sweden where they have major metallurgical industries and several mines.

UNIVERSITY POSITION

DS: Then in 1954, after you graduated from college, you got a position in the Faculty of Chemical Engineering at the Technical University of Copenhagen. How did that happen?

VB: I served compulsory military service from May 1953 to November 1954 in the Corps of Engineers. It was one of my teachers at the university who told me, while I was still enrolled in the Army, that he had a project with a task which he would like me to work on involving friction and lubrication of metals for turbines and large diesel engines. I said okay. So when I returned from the army I took that position. It did not go to my heart. I felt I was so alone, the next laboratories were Glasgow, London, and Düsseldorf, and they were groups of 20 or more.

DS: Essentially the position came to you.

VB: Yes, there was a lack of metallurgists at the time so jobs were coming to them. Then along came the Thule meteorite and I had to persuade Professor Børge Lunn that I would have to slow down his work so I could spend time on the meteorites. I was independent of him by then because he had become director of a large company and left the university.

DS: But you remained at the Technical University?

VB: Yes, I stayed at the Technical University for 43 yr.

DS: There was no problem you converting to meteorites?

VB: Well, it took some time before my colleagues were convinced that it was worthwhile. I was alone in Denmark as the only meteorite researcher, certainly at the Technical University there was no one else. Then came all the space missions and slowly people could see the interest in meteorites.

DS: So as the space program heated up meteorite research became more palatable to the people at the university?

VB: Yes, I think so.

DS: You have had a career of working alone? You have never been part of a large group.

VB: No. I have had numerous students work with me for a few years who then moved into careers in industry, and I had a good friend, Professor Henning Sørensen in geology, who supported me.

DS: Could you argue that iron meteorites are a good way to learn metallurgy?

VB: No, you need to learn about casting, welding, and so on.

DS: Did you encourage them to go into industry?

VB: Yes. Iron meteorites have been fun and interesting, but there are simply very few jobs.

DS: Would you say studying meteorites has harmed your career at the university, in terms of going up the promotion ladder?

VB: No. I have enjoyed the freedom to become deeply involved in the subject, and I have had the necessary freedom to travel.

DS: You have merit raises?

VB: Yes. My merit raises have been better than the raises due to promotion.

DS: That seems odd. Why did you not get promoted to full professor if you had better merit raises?

Fig. 2. Two knives acquired from Eskimos by Ross and now in the British Museum (numbers 87561 and 87562). Flakes of the Cape York meteorites have been cold hammered and inserted into long grooves in the walrus handles. Scale bar 50 mm. (Courtesy Natural History Museum of Denmark, University of Copenhagen.)

VB: Because I never ran a big group and Denmark was too small for a full professorship. Full professors have many post docs, technicians, and students. They have large groups. Twenty or more.

DS: So you spent 5 or 6 yr at the university teaching metallography, and then in 1961 you start to get involved in expeditions again. How did that happen?

EXPEDITIONS TO GREENLAND (1961–1965)

VB: I had the experience with the Thule meteorite. I started to read the literature about Greenland—I had always been interested in Greenland—and I read about Peary's expeditions. Here's his book, *Northward Over the Great Ice*. He wrote in the last chapter that he had found all the meteorites and taken them to New York and there were no more, but he had no maps, just text and photographs. The Eskimos knew a lot about these meteorites, they were very familiar with them. They used one of them as an anvil. I showed you the photographs of knives they had made (Fig. 2). Slowly I got a general idea of where the Peary meteorites were found, and I knew where the Thule meteorite was found, so I got an idea of where to look for more meteorites. I got samples of the three meteorites Peary brought back in 1895 and 1896 and compared them chemically and structurally with Thule and concluded that they were from the same fall and that it was so big there might be more to find. I thought there was a 100 km long fall ellipse. So in 1961 I went to the department and asked if I could go to Greenland to look for meteorites. The Minister of the Interior said I could go up there as "the spy of the year."

DS: Spy of the year?

VB: He said it with a smile. Thule airbase was about 10,000 people, mariners, airmen, and so on. There were aircraft taking off and landing all the time and there was a steady flow of people in and out testing, surveying, building huts, drilling the ice to make wells for water, trying methods for moving heavy loads over crevasses (there were lots of crisscrossing crevasses), experimenting with communications under the ice, and all sorts of other activities. They even had an atomic reactor. My task was to represent the Danish government on the base and to report back to them on the American activities. It was a military base but I was the Scientific Liaison Officer.

DS: So you were there for July and August, nominally to watch what the Americans were doing but it gave you enough time to look for meteorites.

VB: I had a military rank so I could move about freely about the base. The officers bought me drinks in the bar. They brought me this signal horn and encouraged me to drink cognac from it in order to be initiated into the group. It was great because I made many friends and they were very helpful when I needed anything. I could request a helicopter to go anywhere, and these helicopters always flew in pairs for safety.

DS: How did you go about hunting for meteorites?

VB: I walked everywhere. I had a driving license from the U.S. government and I could take a military vehicle, but for most places I had to walk. Mostly I spread the word that I was looking for meteorites. I heard stories of meteorites having been cut up and distributed to people on the base.

DS: You went next year?

VB: Next year my mother was sick and I could not go, but I went again in 1963 and the word had spread. I was given reports of a 7–8 kg meteorite, which I eventually saw. I went around the base and began to explore farther from the base. I had a motorboat to get me to farther locations where I could then search on foot. I looked especially for areas where the snow had melted recently, and I avoided places where lichen and small plants covered the rocks, because this indicated that such areas were free of snow most of the summer, and probably were well known to the Inuits. I tented and was alone most of the time.

DS: You found Agpalilik on July 31st 1963? How did that happen?

VB: I was searching on foot and sat down to take a rest, and just below me on the slope was this rust colored rock that was quite different to everything else. It was the meteorite. I checked it with a magnet—I always carry a magnet—and it checked out. I was certain this was an iron meteorite. It was mostly buried but enough stood out for me to easily see it from 10 to 15 m distance.

DS: How far is this from Peary's meteorites?

VB: About 6 km. Very close. And look at the map (Fig. 3), see all that sea? There must be many meteorites out in the sea. I came back with a team of

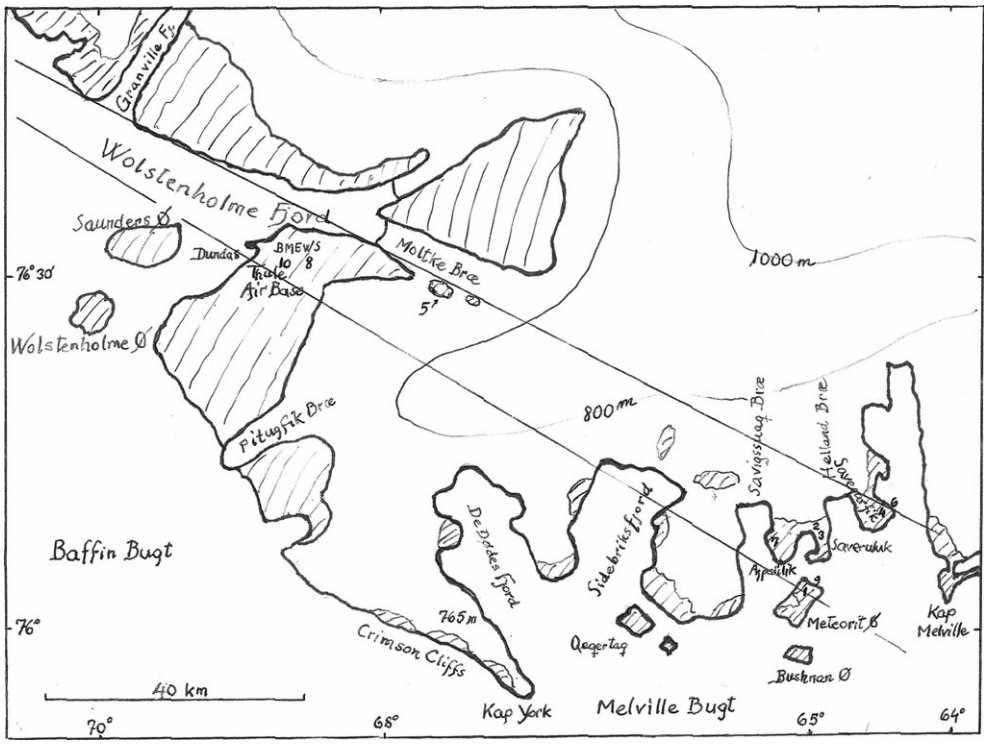

Fig. 3. Hand-drawn sketch map used by Vagn Buchwald to identify meteorite locations. The two diverging diagonals represent a possible strewn field starting in Wolstenholm Fjord and ending in Melville Bay. Shading refers to ice-free regions, the ø symbol means "island," contour lines are shown inland at 800 m and 1000 m. The numbers 1–10 locate individual meteorite find sites: 1, Ahnighito; 2, Woman; 3, Dog; 4, Savik (I); 5, Thule (I); 6, Savik (II); 7, Agapalilik; 8, Thule (II); 9, Tunosput; and 10, Thule (III). Note the location of Thule Air base, where two meteorites were recovered.

Eskimos, they do not look for meteorites. They are interested in hunting seals and polar bears. On one occasion a bear came into our camp. The Eskimos shot it and I could not stop them. The bear tried to swim away but they could catch it with lassoes. The person who first saw the bear took the thick skin around the neck, then the next person took the claws, and finally the meat was preserved under rocks to be fed to the sledge dogs.

When I got back to Denmark, I went to Danish television and radio and told them about the meteorite and asked them if they wanted to record its recovery in 1964 but they refused; it would require a team of six and would be too expensive.

DS: Nowadays they would send one reporter with a video camera.

VB: Here is a map with all the meteorites indicated. Agpalilik was near the coast. Much later, the Inuits found another meteorite in the sea. They found it in the sea at low tide. They reported it to me and I told them to keep it, we have plenty in Copenhagen. It is now in the Greenland Geological Museum.

DS: How did you get Agpalilik back to Copenhagen?

VB: We built a sledge in Copenhagen that could be dismantled into 100 kg pieces, the maximum our team could lift, and shipped it to Thule. Then in 1965 we rebuilt the sledge under the meteorite. The meteorite was buried in permafrost so you could do nothing with your hands. So we drilled holes in the rock and dropped dynamite into the holes. We were a team of eight as we freed the meteorite from the ground, we supported it with timbers and lifted it with jacks. Digging around the meteorite and inserting timbers was dangerous. If it tumbled it could kill someone; there was nothing we could do if it moved. But slowly we lifted the meteorite until it was level with the terrain, which meant lifting it about 6 feet, and then we welded the sledge together around the meteorite.

I also got around in a small motor boat; there is an island, we call it Meteorite Island, where about 64 people live and they let us hire a motor boat. Then we had to return home because the ice closed in. The skipper said that we need to get out of there. Then we had an issue about the large amount of unused dynamite. The Inuits said just leave it there, but I said under no conditions would we leave it, so we took it with us on this little boat. That was fortunate because

our boat became frozen in. We went out on the ice and made a narrow channel for the boat by exploding dynamite. We had brought champagne to celebrate recovery of the meteorite, but instead we drank it to celebrate our release from the ice.

DS: And then?

VB: In 1965 we had moved the meteorite to the coast ready to be picked up (Fig. 4). We could not pick it up that year because we needed a large ship and it could not get close enough to the coast. The ice condition was not good enough. The same happened in 1966. In 1967, I was in Arizona to study the iron meteorites, so I did not go to Greenland. However, Captain J. E. Leo on M/S Edith Nielson organized the collection of the meteorite. They hauled the meteorite into an American landing craft, using a winch on the craft, and taking the weight of the meteorite with pulleys uphill. That was scary because as soon as the meteorite reached the door of the landing craft, the back of the landing craft went up and water began flowing into the boat. It took very fast reactions; they were winching while pushing the landing craft doors closed. But they got it to the big ship and the ship's hoist lifted it, still on the sledge, into the hold. Even the big ship tilted over a little under the weight of the meteorite. It was about 20 tons.

DS: So you found a Danish ship that could hoist the meteorite from the American landing craft?

VB: Oh yes, every summer there were Danish ships in the area servicing the Thule base. Then the ship brought the meteorite to Copenhagen.

DS: You have written up these details in a number of places.

VB: The best account of the recovery of the Agpalilik meteorite is a chapter in a 2012 book called *Greenland's Power of Fascination*, but there is also a complete account in my 1992 meteorite textbook *Meteoriter*. They also tell the history of Greenland exploration and the Cape York meteorites. Unfortunately, these accounts are in Danish. The best account in English is in my *Handbook*, but it is fairly brief.

DS: So the meteorite got back to Copenhagen in September 1967.

VB: Yes, by then I was in Arizona working on the *Handbook*.

THE HANDBOOK OF IRON METEORITES

DS: Let's talk about the *Handbook* (Fig. 5). First, what prompted you to write it?

VB: I started to describe the collections in the Copenhagen Museum, stones and irons, and it pretty soon became clear to me that I was going to have to concentrate on the irons because that was my own area of research. So I started to organize the Danish collection. Then I stumbled across a book published by E. P. Henderson, that great man of meteorites, on the iron meteorites in the national collection in Washington and I decided to publish something on the iron meteorites in the Danish collection. Then there was a conference in Moscow and several people came from the United States. One was Carleton Moore who said to me that he had a collection in Arizona that needs describing. I had to go home and ask permission. I asked whether it would be possible to take a 1-yr sabbatical to go to Arizona. Well, it was possible. So I spent a year in Tempe [the Arizona State University's Center for Meteorite Studies] and I described 50 irons in the collection. This is how it started. Moore wanted more, we had a fine time.

I soon realized that, for the curators, this was very interesting, so I thought I would continue. At the end of July 1968, my family and I took a month to travel by car from Arizona to Washington where Brian Mason took care of me for the next 22 months. We went up to Canada, we saw a park full of dinosaur bones, saw lots of farmland, Niagara Falls, and finally on to Washington and the U.S. Natural History Museum where we met the curator Brian Mason. I spent 2 yr working through the Smithsonian Collection. I had all the help I needed. I found new meteorites in their collection. It was exciting work. There were files in the museum that were essential, and there were maps, so I could find out exactly where these meteorites came from. I had to learn a lot about these objects. I had to know the old systems for classification. I wrote everything in long hand and then when I returned to Denmark I found a young woman who corrected my English and typed it all up. The manuscript was ready in 1972. In the mean time I also visited the Vatican Collection in Rome, and collections in Torino, Geneve, Milano, Paris, Prague, Moscow, Leningrad, and many other cities.

DS: While you were based in the States you visited various non-U.S. collections.

VB: Yes, I visited Mexico and Canada, places far from Arizona State.

DS: So your university gave you a 3 year sabbatical, paid for by the Danish state?

VB: I had a NASA grant and a Fulbright grant, for travelling with my family. The pension from the Danish state was maintained, but I got no wages from Denmark while I was in the U.S. I also had support from the Carlsberg Foundation.

DS: Now each entry in the *Handbook* has a history of the sample, a description of the sample, and which collections have that sample.

Fig. 4. Recovery of the Agpalilik meteorite, one of the Cape York meteorites. This is a time sequence running top to bottom left and then top to bottom right, the time period being 31st July 1963 to September 1967. The images show excavation with the help of Eskimos and dynamite, jacking up and building onto a sledge, hauling to the coastline, winching onto a U.S. Air Force landing craft, hoisting onto the M/S Edith Nielsen Danish supply ship, and placing on a truck for transfer to the Geological Museum of the University of Copenhagen.

VB: Yes, and the chemical composition. I only listed analyses that were good in my opinion. If I did not believe a result in the light of my observations I left it out. There were people who wanted me to list everything, but I didn't. It is very difficult to analyze meteorites, not everyone can do it. You would be amazed how difficult it is.

DS: Why is that?

VB: Because it is difficult to separate nickel, cobalt, and iron. They are so similar to each other.

DS: You are talking wet chemical methods. But the DMG test for nickel is pretty reliable?

VB: Yes, but it is difficult to make it quantitative. Cobalt is even more difficult. Jarosewich could do it.

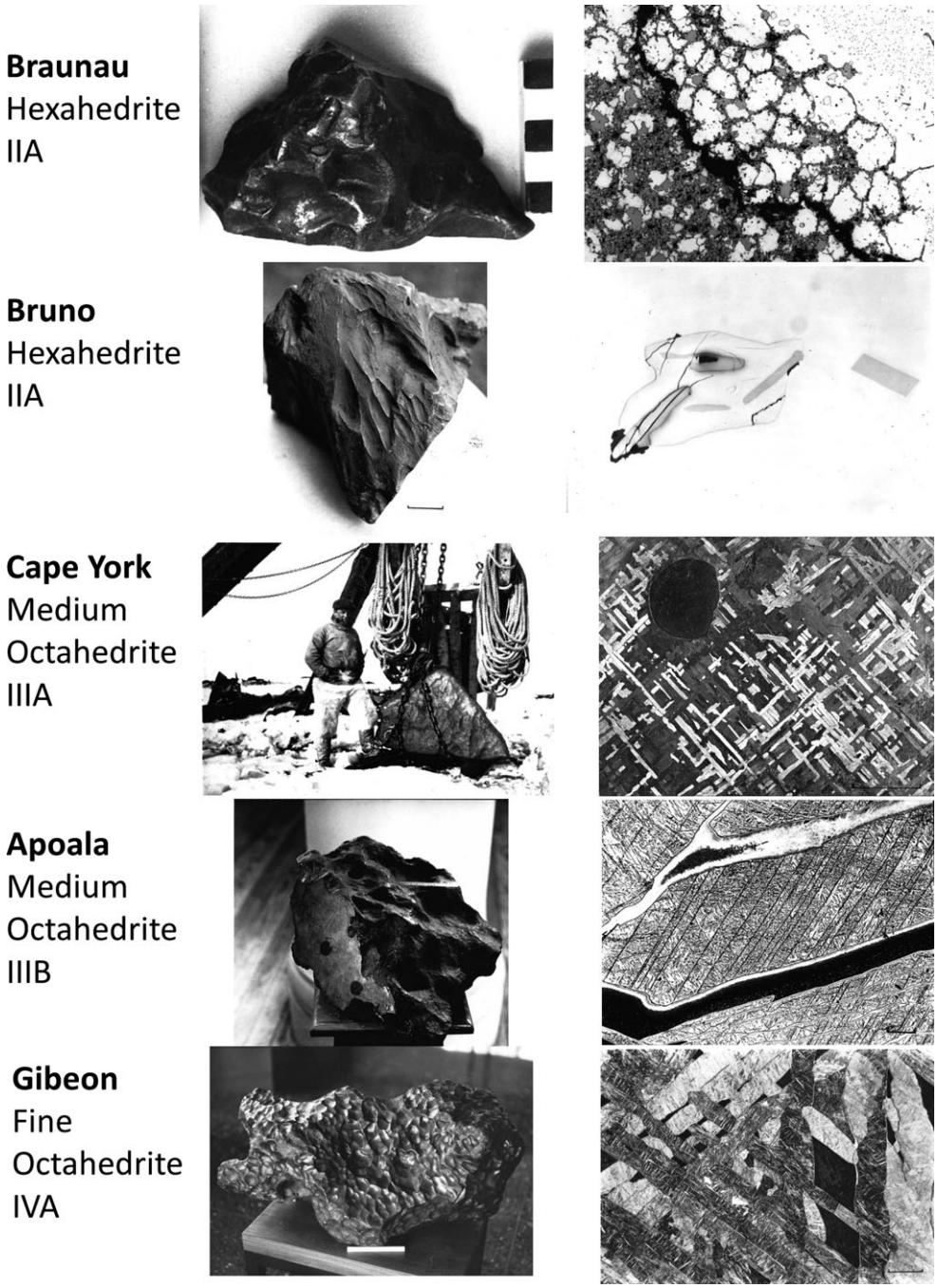

Fig. 5. The *Handbook of Iron Meteorites* is a three-volume description of the history, structure, availability, and composition of virtually all of the iron meteorites known at the time. Some representative irons are shown here. Braunau, Bohemia, fell July 14, 1847, end piece 915 g, Tübingen. The section shows a shock-melted troilite-daubreelite-schreibersite nodule, 600 μm horizontal field of view. Bruno, Canada, found 1931, scale 3 cm, Tempe, Arizona. The section is a 0.2 mm long cohenite crystal with schreibersite inclusions and a rhabdite crystal to the right. Cape York, Greenland, the 3.4 ton Savik I mass being recovered by Holger Blichert-Hansen. The section shows the typical Widmanstätten structure and a 35x30 mm troilite inclusion. Apoala, 78 kg mass in Mexico City, found 1889, scale on the meteorite is 10 cm. The section shows shock-hatched kamacite, scale bar is 0.1 mm. Gibeon, Namibia, 350 kg Lichtenfels mass, Max Planck Institute, Mainz, length of ruler 15 cm. The section shows shock-hatched kamacite in the Ganigobis mass, scale bar 0.5 mm. The original prints for the figures in the *Handbook* were preserved by Vagn Buchwald and have been scanned by the Natural History Museum of Denmark. They can be accessed by figure number: http://geologi.snm.ku.dk/english/samlinger/meteorit/handbook-iron-meteorites/search/.

DS: There was John Easton in London, and Wiik in Finland.

VB: Not many, and Birger Wiik was strongest in stony meteorites.

DS: How successful was this structure for each entry? Did it always work or sometime fail?

VB: There are many instances where we know little about the history. For example some samples had been heated by blacksmiths. The meteorite just appeared in a collection without paperwork. Often during the war all the papers were lost. Berlin, for example.

DS: I was going to ask you about Berlin.

VB: That was a major problem. After it was known that I had organized many collections, Professor Hoppe of the Humboldt University in Berlin asked me if I could come to Berlin in 1977 because he had a problem. I said of course, even though it was behind the Iron Curtain. I thought that the Russians had taken all the samples. However, when I got to Berlin I found out that during the war one of the assistants had packed up the meteorites and moved them to a cave in a salt mine for safe keeping. He was killed in the war and all the paperwork had deteriorated during storage in the cave. There were about a hundred meteorites and I said to Professor Hoppe that I would try to find out what they were. The way to find out was that I knew what iron meteorites had been on the market in the nineteenth century for exchange and sale. I had numerous catalogs from the nineteenth and early twentieth century. Most museums keep records of purchases and exchanges, list prices, and they had survived. So I had a box of 100 meteorites, which I sorted and weighed. The weight was important because it is always recorded during transactions. I was able to identify 95 of the meteorites.

DS: The remainder is still in the collection unidentified?

VB: I think so. I was there a month ago but unfortunately the meteorite collection is not well displayed.

DS: There is a trend nowadays to make elaborate visual displays that educate and appeal but hide the artifacts. I was at the Science Museum in London recently and you could not see Herschel's telescope because it was hidden by a cardboard cutout of Herschel. The designers have overwhelmed the historians.

What I would like to do now is run through some of the institutions you acknowledged in the *Handbook* and if you recall anything interesting about your dealings with them you briefly mention. British Museum.

VB: I never worked in the British Museum. Robert Hutchison sent me many samples as temporary loans. He was very helpful. He had several major specimens that I could not get anywhere else. Nininger split his collection between the British Museum and Tempe so many of their samples were duplicates of samples I had already seen in Arizona.

DS: Mainz.

VB: Mainz, I was there for half a year in 1974. I had seen most of their samples in the U.S. because Glenn Huss split his collection between Vienna and Mainz. I had much help from Professor H. Hintenberger, Hans Voshage, and H. Wänke.

DS: Harvard.

VB: They sent me some samples on loan, and I had many good conversations with Ursula Marvin.

DS: Washington.

VB: I spent 2 yr there. Many of their samples were new to me, and I had fine cooperation and support by Roy Clarke, Brian Mason, Joe Nelen, Phyllis Brenner, Eugene Jarosewich, and the assistants in the preparation of hundreds of specimens.

DS: I know about one case, they were Arkansas meteorites; Joe Wright Mountain and Sandtown had been previously paired but you showed they were different meteorites since their metallography is quite different. Field Museum.

VB: Ed Olsen, in Chicago, had a 100 kg meteorite, Santa Rosa, that they had had for 100 yr but which had never been cut. They did not know how to cut the meteorite. So I arranged for it to be cut. Ed sent me the main mass with permission to cut a slice off. I had to find a machine shop. Again it is the irregular shape that is the problem.

DS: What about Yale?

VB: They sent me some samples. Small but useful.

DS: What about other U.S. collections?

VB: The keeper of the James Monroe Law Office and Museum in Fredericksburg, Virginia, was kind enough to let me examine a pair of pistols donated to President Monroe by the young Argentinian Republic in 1816. They were said to have been forged from the Argentinian meteorite Campo del Cielo, but they were not. They were made of ordinary wrought iron.

DS: Tübingen?

VB: They sent samples on prolonged loan.

DS: Let me digress for a second, most curators assume their collections are well looked after, so how did they react to you coming in and reorganizing their collections.

VB: They invited me. There was a feeling among curators that their classifications were well out of date. In the olden days they would etch them with strong acids and it was hopeless for microscopy, too rough, too concentrated, too long. Okay for naked eye

observation, but hopeless for microscopy. Often they etched names and numbers on the face. Terrible.

DS: Getting back to my list. Leningrad.

VB: I spent a week at Leningrad going through the collection, helped by Professor Grigoriev.

DS: Moscow.

VB: Same thing. I spent a week there. E. L. Krinov, L. G. Kvasha, and Director D. Dorfman were very helpful. In those days I spoke Russian, but I have forgotten most of it now.

DS: Prague.

VB: They had a good collection but it had been damaged by the Russians, and it was all stored away. Every day I would visit the museum and every day I was locked in. Every drawer and cabinet was locked and I had to get a key and I was watched. I could not do analytical work but I could do photography, although the light was terrible. It was one of the most difficult places to work. I was on the S-Bahn 1 day in Prague and I was robbed.

DS: So the big collections were Tempe and Washington; most of your work was done there. Is it true to say that 80% of the samples in the *Handbook* were at those two institutions?

VB: I am not certain. I got a lot of samples on loan through the mail.

DS: So the work took at least 3 yr while you were in the U.S.

VB: Yes, in the beginning I published this small book on Danish meteorites (Buchwald and Munck 1965). Then there was the goose-shaped meteorite from Greenland which I published in *Geochimica*, Thule (Buchwald 1964). For a while I thought it was an independent meteorite, but then came the expedition work and I realized that Cape York was an extended shower more than 100 km in length. There is a farmer here in Denmark, who has spent time at the American airbase in Thule, who has a Cape York meteorite. He has shown it to me. I examined it with penetrating X-rays and saw the troilites. He was free to keep the meteorite because at the time there was no law forbidding it. He has promised me that when he dies it will come to the Geological Museum. It is a very good Cape York meteorite from the northwest end of the field.

DS: So when this article appears in *MAPS* do you think there will be a stream of hunter/dealers going to Thule for meteorites.

VB: They can do it, but under the modern law the meteorites belong to the Greenland government. Whatever they find will have to be given to the Geological Museum. The finder will be given a reward, and the amount may be considerable, but everything must be turned in.

DS: Does this mean people tend not to turn things in?

VB: No, the opposite. They like the reward. It's the same with archeological artifacts; it works well. The problem is that they often damage a meteorite trying to cut it. One Dane tried to cut a meteorite with a welding torch and he destroyed it. His reward was minimal.

DS: So how many years to write the book?

VB: Oh, I think it was about seven in all, and then there was the publication process which added three more years, with two fantastic visits to California to proofread the books.

DS: Eventually it was published jointly by Tempe [Center for Meteorite Studies, Arizona State University] and the University of California. It was clear it was not going to make much money, so money had to be paid up front?

VB: Oh yes, we had to raise the money. The Carlsberg Foundation in Denmark put up a lot of money, Brian Mason in the U.S. arranged for essential funds, and there was Herbert Fales, Arizona. I don't know exactly. I was grateful that Carleton [Moore] handled the money. I asked him to keep me out of it.

DS: The book was published, it did sell out. Mine was $100, a special offer from the publisher who wanted $250. Now it is $1400 on Amazon.

VB: Now it will go down again because it is free on-line.

DS: Yes, I think Ed Scott arranged for it to be scanned. There was a Meteoritical Society announcement. How do you feel about this?

VB: Oh, I think it is great. The more people read it the better. I have a bound copy that includes documents relating to its publication.

DS: Some archivist should want that.

VB: I have donated all my technical books to the Technical University of Denmark.

DS: What has been the fall-out from the publication of the book?

VB: Oh, it has been marvelous. Everyone has seen it, all over the world. Peter Hoeg wrote the novel "Smilla's Sense of Snow" in 1993 inspired by my book. And in 1997 Bille August produced a 2-h film, based on the book by Hoeg.

DS: Do you ever see it being superseded.

VB: No I don't think so. It was a huge task. No one will do it again. I am glad I did it but I would not do it again.

DS: You had a wife and young children when you were doing this. Did they come to the United States with you? How did that work out?

VB: My wife and two young boys came with me and they thoroughly enjoyed it. The children went to U.S. schools and made American friends. It was good.

DS: So a new young Vagn Buchwald comes along in a few years, he or she is in their thirties, and decides to emulate your work, update it with new irons, would you encourage that?

VB: Yes, but they must expect a difficult task. Iron meteorite research can be a frustrating field. After 25 yr of effort we still have not made the Widmanstätten structure, for instance, and I do not think we ever can. The necessary cooling rates are just too slow, degrees per million years.

DS: Well, people have precipitated alpha in the gamma field, with the octahedral orientation.

VB: So have I, but that is not the Widmanstätten Structure. You need to be able to see the macrostructure with the naked eye. That is what I mean by Widmanstätten Structure.

DS: With most silicate systems there is a catalyst available, sodium silicate for instance is used by Gary Lofgren to speed the crystallization of feldspar from feldspathic glass, but there is nothing like it for metal systems.

VB: That is right. But I would rather see a thorough treatment of some of the most interesting meteorites, like Gibeon from Namibia, which displays a number of intriguing structures.

AFTER THE HANDBOOK

DS: After your 3 yr in the U.S. you returned to Denmark and to the Agpalilik meteorite. This is the first large meteorite that has actually been cut so we can see the interior (Fig. 6). Tell me about the cutting.

VB: I knew a stonemason in Denmark who was an expert at cutting granite large slabs for facing buildings. He agreed to try to cut a small iron meteorite. Well, it worked fine. Then there was the issue of time and money. Each cut was going to take 200 h, working round the clock, three men working shifts. One was a violinist, who could judge the cut by the sound. We could see from the rough cut that it was loaded with troilites. I took brass rubbings. That was a real surprise.

DS: Would you say that as soon as the meteorite is larger than say 50 cm, at which point it becomes a display specimen, that we should always cut them open? Should we cut the Willamette meteorite in half? Or at least cut the end off?

VB: I teased Martin Prinz about cutting Willamette, but he would not even think about it.

DS: But if you had your way, you would cut all large iron meteorites?

VB: Absolutely! Perhaps not them all, but most of them. It is important to know whether they consist of one, or two, or many crystals, perhaps in twinning relationships. See for example the large slabs of Mundrabilla that were cut in Heidelberg.

Fig. 6. The Agpalilik meteorite section as it now appears on display in the Geological Museum in Copenhagen.

DS: The orientation of the troilite was significant.

VB: Very much so. The Cape York iron crystallized in a gravity field. This is very important. We published several papers on that (e.g., Kracher et al. 1977; Esbensen and Buchwald 1982; Esbensen et al. 1982a, 1982b).

DS: Can we get a gravity field estimate from the troilites, they had mineralogical fractionations.

VB: I could not. That is a job for my successor.

DS: Your last expedition to Greenland was 1966. What other expeditions have you been on?

VB: I arranged my own expedition to Chile in 1973. I visited the Monturaqui Crater but it was very old. The meteorite fragments were much corroded.

DS: How did that expedition come about?

VB: It was funded by the university and there were just three of us. I wanted to know whether the crater was produced by an iron meteorite. We found that it had been. We visited the museums. They had many meteorites recovered from the open cast saltpeter mines.

We visited the Vaca Muerta site. Later, Holger Pederson did much work there (Pederson 2012).

I also went to South Africa and Namibia. I did not collect anything, but I described what they had in museums in Cape Town and added the descriptions to the *Handbook* as an addendum of 30 meteorites. I exchanged Cape York material for Gibeon. I wanted to map the location of all the Gibeon irons but the data were just not available. The inhabitants had been nomadic and sold the meteorites for a long time. I wanted to know where the strewn field was and whether there was a crater somewhere, but I could not do it. The Namibia expedition was difficult. There was a civil war going on and you needed a permit to buy gasoline etc. And the sand got everywhere!

DS: Your interest in expeditions is to find new scientific samples or to enhance the Copenhagen collection?

VB: My interest was scientific. The Geological Museum in Copenhagen has benefited from the material I collected and exchanged small Cape York samples for foreign meteorites. I worked at the Technical University which is where all the cutting, hardness testing, preparation, and photographic work were done. I deeply appreciate the support of Professor E. Knuth-Winterfeldt who was in the chair of Metallurgy.

As far as expeditions are concerned, Kirsti and I went on an expedition in Central Australia with Shoemaker after the Meteoritical Society meeting in Perth in 1990. Kirsti was voted the best of 50 participants on the trip; she was so helpful, cooking, organizing, and putting up tents.

DS: You went on one of the Antarctic expeditions. How was that?

VB: I did, in 1982–1983, but I would not go again. It is for people sportier than me. The year I went Bill Cassidy had a new instrument called GPS which was secret and he was to test under Antarctic conditions. I don't know what the result was. We brought back several hundred meteorites, but no irons. From my point of view it was disappointing because you were just a collecting machine; you found the meteorite and could not touch it. It was picked up with gloves and placed immediately in a bag and you never got to see it. The other problem was that the light was so difficult. Everything is so bright on the Blue Ice. At one point I asked a New Zealand party if they could take me up in the helicopter so I could see mountains instead of Blue Ice. After a while I asked them if they could land on a glacier. They did, and I immediately picked up a 1 kg meteorite. They are everywhere. It was called Taylor Glacier and at the time it was the only meteorite with that name. It is now part of the U.S. collection at Houston or Washington.

DS: After your Greenland experiences you were used to being free to do what you wish, but with the Antarctic meteorite program you were a relatively small part of a team. How did Antarctica compare to Greenland?

VB: Antarctica is very different to Greenland. Greenland is beautiful with lots going on, lots of geology, lots of animal life, few tourists. Antarctica is barren, with tourists!

DS: It would be nice if you would publish more details on your expeditions. There are only a few articles on your expeditions.

VB: That is right, I have published little.

OTHER IRON METEORITE RESEARCH

DS: Before we talk about your nonmeteorite work, I know you have published many meteorite research papers in the 1970s and 1980s (e.g., Buchwald 1980; Albertsen et al. 1983; Buchwald and Mosdal 1985a, 1985b; Easton et al. 1987). Can we talk about those?

VB: I wanted to bring order and a system into this huge amount of material, scattered all over the world, and of which—it turned out—some had been reheated and maltreated by early owners. One of the things I consider important is that I cleared up the mess with Mexican meteorites. There were so many names, so many collectors involved, like Ward, that it was very confusing. I talked about this at a Geological Society of America meeting (Buchwald 1968).

DS: There is a *Phil Trans* paper on the mineralogy of iron meteorites (Buchwald 1977).

VB: I was invited to that meeting and to write that paper.

DS: ... and one of phosphate minerals (Buchwald 1984). In fact, you have discovered, or been involved in the primary characterization of, five new minerals (roaldite, $[Fe,Ni]_4N$, Nielsen and Buchwald 1982; carlsbergite, CrN, Buchwald and Scott 1971; akaganeite, $Fe^{3+}O[OH,Cl]$, Post and Buchwald 1991; and hibbingite, $[Fe,Mg]_2[OH]_3Cl$, Buchwald and Koch 1995; arupite, $Ni_3[PO_4].8H_2O$, Buchwald 1990). Can you something about these?

VB: Yes. Perhaps I was inspired by that phosphate paper (Buchwald 1984) when, in 1987, I worked with corroded Santa Catherina material and discovered a beautiful blue mineral that turned out to be a nickel-analogue of vivianite. I honored the eminent Danish corrosion engineer Hans Aruep, by naming it arupite on his 60th birthday.

DS: And you have had a mineral named after you, buchwaldite (Olsen et al. 1977).

VB: Yes, that was an honor.

DS: You have published with Malvin, Esbensen, Scott, and Wasson (Schaudy et al. 1972; Scott et al. 1973; Esbensen and Buchwald 1982; Esbensen et al. 1982a, 1982b). Tell me about those. At the time there was this series of papers coming out on the compositional classification of iron meteorites.

VB: Most of what I contributed was already to be printed in my *Handbook*.

John (Wasson) and I wanted to tie together his chemical classes with structure. John wanted to completely throw out the old classification scheme, but I preferred to keep it. There are just so many anomalous irons in his classification scheme. That limits its usefulness to curators.

DS: Well, there is genetic information in the compositional classification. Structure takes you so far, but John would want to say that Ga and Ge is telling us something you can't see with metallography.

VB: I completely agree, but you need structure. Goldstein made a useful contribution with cooling rates and improved phase diagrams, which was very helpful and was better than mine (Goldstein and Short 1967).

DS: Parent body sizes?

VB: The astronomers can tell us how big asteroids are.

DS: It sounds as though you are more interested in describing these meteorites than determining their history and origin.

VB: I can't do any more.

DS: Can you tell me more about why you haven't gone more into, say, parent body size, origins.

VB: It takes more mathematics than I have. Other people can do it better.

RESEARCHERS, COLLECTORS, AND THE PROGRESS OF IRON METEORITE RESEARCH

DS: At one point in our conversations you were quick to add the private collector when I said your work is of value to museum curators. Tell me more about that, the relationship between researchers and dealers and collectors.

VB: I am very relaxed about this. It is not a problem for me. I remember some researchers get very upset when a dealer cuts up a meteorite and sells the slices. Nininger caused a lot of upset. But I have no problem with this. So long as they don't destroy the meteorite, I have no problem. The collectors go places other people would not go, like the deserts.

DS: They have a role in acquiring new meteorites and it is not clear that all meteorites will otherwise ultimately find their way to museums.

VB: The problem is when private collectors die their collection is either lost or gets poorly looked after. I have seen so many meteorites in small collections that have no labels, or the wrong labels. Often the private collections are donated to local museums that do not have the expertise for good curation.

DS: This is a new argument. I have heard many arguments for and against the private meteorite trade, but the danger that private collectors do a good job in their lifetime but afterwards their collections fall into unsuitable hands in museums is new to me.

In terms of iron meteorites, putting your own work aside, what do you think have been the major developments since you entered the field?

VB: I would say the work of John Wasson and Joe Goldstein has been important. So has the analytical work of H. Voshage and Eugene Jarosewich. We have a group in Copenhagen under Henning Haack, and I am expecting much from them. There is some cratering work going on. That is important, finding craters associated with iron meteorites. They are busy in Canada, Norway, and Finland.

Otherwise, I think the major advances have been within stony meteorites, meteorites from the Moon and Mars, and age determinations, where I have not been able to assist.

ARCHEOLOGICAL METALLOGRAPHY

DS: Well, we have reached about 1990 and your interest turns away from meteorites and towards Danish archeology. Talk to me about that work.

VB: Well there were supposed to be many knives and weapons made from meteorites in the museum collections, but I never found anything. However, I realized that the archeologists needed some help in understanding metallic artifacts. Corrosion is a big problem with artifacts, and I had considerable experience with corrosion in meteorites (Fig. 7). They knew very little. They have many ways to examine other materials, bones, pottery, manuscripts, but nothing for metallic objects. So I offered courses, and many students and conservators took them, and during that process I got permission to take ancient nails and bronzes from the collections for analysis. I found chemical ways of distinguishing iron from Denmark, Sweden, and Norway from the composition of the slag inclusions. Not the metal, but tiny inclusions of slag. I can infer whether an iron artifact is from Denmark, Sweden, or Norway.

Fig. 7. The Ballinger, Texas, meteorite showing corrosion attack on a polished surface, exposed 24 h in an indoor environment. The orange, circular steps are about 0.2 mm in diameter and contain 2–5% chlorine (Page 522 in Buchwald 2008). (see online version for color figure.)

DS: Besides a chemical analysis of the slag, you could do metallography of the iron by polishing and etching.

VB: Yes, you could see how they hardened the steel from the location of the martensitic structure and I have made good use of hardness testing machines. There were many different tools (Fig. 8). You could see which weapons had been used in battle from the damage. Some of these weapons were described by Tacitus.

So in 2005 and 2008 I published two books describing about 30 yr of work on archeological artifacts (Buchwald 2005, 2008), one from ancient times to about 1000 A.D (*Iron and Steel in Ancient Times*), and one from 1000 to 1850 when Bessemer invented his furnace (*Iron, Steel and Cast Iron before Bessemer*).

DS: So in the first book you start with iron meteorites, then the Bronze Age, the Iron Age, phosphorus, and then carbon. In the second book you carry this forward to the nineteenth century. They are large books and they are in English.

VB: There is so little published. These are the only books on the history of iron and steel in Scandinavia.

DS: It seems to me, just leafing through the books, that you take a similar approach to the *Handbook of Iron Meteorites*, instead of just summarizing the history and each type of metal you report new observations of the metallography and electron microprobe analyses with interpretation of the data and metallographic observations.

VB: Yes, it is largely historical with some modern analyses of the materials.

DS: These were published by the Danish Academy of Sciences. You retired in 1998, but you have written these two major books since then.

Fig. 8. A Roman dagger, a so-called pugio. From a grave, about 50 A.D., at Hedegaard, Jutland. Corrosion has sintered the dagger to other grave gifts, a pair of scissors, and a knife (Page 190 in Buchwald 2005).

VB: Yes, I am still writing, and I love it, but I cannot get sections made for microscopic examination. That is a problem. I also miss my old colleagues and the students at the university.

DS: Several times in this interview you have mentioned your wife Kirsti (Fig. 9). It sounds as though she has been critical in your career?

VB: I am happy that she is critical with everything I do!

DS: Well, Vagn. I have worked through all of my notes. Do you feel we have successfully captured your career?

VB: Yes, but I would like to end by recalling a memorable visit to my old friends at the Smithsonian in 1987. I had 3 months leave of absence and heard at my arrival about the long-standing problem of the mysterious large Port Orford meteorite, hidden somewhere in the Oregon Coastal Range. Roy Clarke, Howard Plotkin, and I made a concerted effort and succeeded in explaining the meteorite away as a cunning

Fig. 9. Vagn and Kirsti Buchwald at their home in Gentofte, Copenhagen, in February 2014. On the right, Vagn has opened one of the dozen or so boxes containing images produced in preparing the *Handbook of Iron Meteorites*.

scientific forgery (Buchwald et al. 1993). I shall not forget how relieved Roy was when we finished that paper, so that he in the future would be able to dismiss the endless number of questions that the Smithsonian got from eager meteoriticists planning to travel to Oregon to find the meteorite.

DS: Well thank you, and thank you very much for being part of this project.

Acknowledgments and notes—This interview was recorded on February 2nd and 3rd, 2014, in Gentofte, Copenhagen, and edited by the author and VFB. I am grateful to NASA for financial support and to Ed Scott, John Wasson, and Hazel Sears for reviews and Hazel also for proofing.

Editorial Handling—Dr. Edward Scott

SELECTIVE BIBLIOGRAPHY

(Papers representative of Vagn Buchwald's career)

Buchwald V. 1965. Heat-treated iron meteorites in museum collections. *Geochimica et Cosmochimica Acta* 29:603,IN7–604,IN8.

Buchwald V. F. 1966. The iron-nickel-phosphorus system and the structure of iron meteorites. *Acta Polytechnica Scandinavica* 51:7–46.

Buchwald V. F. 1971. A new cutting technique for meteoritic irons. *Meteoritics* 6:27.

Buchwald V. F. 1975. *Handbook of iron meteorites: Their history, distribution, composition, and structure*. Volumes 1, 2 & 3. Arizona State University, Center for Meteorite Studies, and Berkeley: University of California Press. As of April 2014, this book is on-line at http://evols.library.manoa.hawaii.edu/handle/10524/33750

Buchwald V. F. 1992a. On the use of iron by the Eskimos in Greenland. *Materials Characterization* 29:139–176.

Buchwald V. F. 1992b. *Meteoritter: Nøglen til Jordens fortid*. Nørhaven, Viborg: Gyldendal.

Buchwald V. F. 2012. Meteoritter og inuitter i Nordvestgrønland. Grønlands Fascinationskraft. Kgl. Danske Videnskabernes Selskab, Ed. M. A. Nielsen, side 21-38.

Buchwald V. F. and Leisner P. 1990. A metallurgical study of 12 prehistoric bronze objects from Denmark. *Journal of Danish Archaeology* 9:64–102.

Buchwald V. and Sørensen H. 1961. An autoradiographic examination of rocks and minerals from the Ilímaussaq batholith, South West Greenland. *Bulletin Grønlands Geologiske Undersøgelse* 28:35. (also Meddelelser om Grønland 162(11)).

REFERENCES

(Papers referred to in the text but not in the Selective Bibliography)

Albertsen J. F., Nielsen H. P., and Buchwald V. F. 1983. On the fine structure of meteoritical taenite/tetrataenite and its interpretation. *Physica Scripta* 27:314–320. doi:10.1088/0031-8949/27/4/015.

Buchwald V. 1964. A new Cape York meteorite discovered. *Geochimica et Cosmochimica Acta* 28:125–126.

Buchwald V. F. 1968. *A reclassification of Mexico's iron meteorites* (abstract). Geological Society of America Annual meeting, Mexico City.

Buchwald V. F. 1977. The mineralogy of iron meteorites. *Philosophical Transactions of the Royal Society, Series A* 286:453–491.

Buchwald V. F. 1980. Seven shock-transformed hexahedrites, sensitive to grainboundary corrosion. *Zeitschrift für Naturforschung, Teil a* 35a:361–369.

Buchwald V. F. 1984. Phosphate minerals in meteorites and lunar rocks. In *Phosphate minerals*, edited by Nriagu J. O. and Moore P. B. Berlin: Springer. pp. 199–214.

Buchwald V. F. 1990. A new mineral, arupite, $Ni_3(PO_4).8H_2O$, the nickel analogue of vivianite. *Neues Jahrbuch, Minerlog. Monatshefte*, 2:76–80.

Buchwald V. F. 2005. Iron and steel in ancient times (Vol. 29). *Kongelige Danske Videnskabernes Selskab* 29:1–372.

Buchwald V. F. 2008. Iron, steel and cast iron before Bessemer (Vol. 32). *Kongelige Danske Videnskabernes Selskab* 32:1–596.

Buchwald V. F. and Koch C. B. 1995. Hibbingite(Beta-$Fe_2(OH)_3Cl$), a chlorine-rich corrosion product in meteorites and ancient iron objects. *Meteoritics* 30:493.

Buchwald V. F. and Mosdal G. 1985a. Meddelelser om Grønland. *Man and Society* 9:1–49.

Buchwald V. F. and Mosdal G. 1985b. Meteoritic iron, telluric iron and wrought iron in Greenland. Meddelelser om Grønland. *Man and Society* 9:1–49. Copenhagen: Commission for Scientific Research in Greenland.

Buchwald V. F. and Munck S. 1965. Catalogue of meteorites in the Mineralogical Museum of the University, Copenhagen. *Analecta Geologica* 1:1–81.

Buchwald V. F. and Scott E. R. D. 1971. First nitride (CrN) in iron meteorites. *Nature Physical Science* 233:113–114.

Buchwald V. F., Clarke R. S., and Plotkin H. 1993. The Port Orford, Oregon, meteorite mystery. A mystery solved: The port Orford meteorite is an Imilac specimen. *Smithsonian Contributions to the Earth Sciences* 31:25–43.

Easton A. J., Claugher D., and Buchwald V. F. 1987. Plessites and associated structures in the Cape York iron meteorite revealed by chlorine corrosion. *Micron and Microscopica Acta* 18:101–105.

Esbensen K. H. and Buchwald V. F. 1982. Planet(oid) core crystallisation and fractionation—Evidence from the Agpalilik mass of the Cape York iron meteorite shower. *Physics of the Earth and Planetary Interiors* 29:218–232.

Esbensen K. H., Buchwald V. F., Malvin D. J., and Wasson J. T. 1982a. Systematic compositional variations in the Cape York iron meteorite, vol. 46. *Geochimica et Cosmochimica Acta* 46:1913–1920.

Esbensen K. H., Buchwald V. F., Malvin D. J., and Wasson J. T. 1982b. Systematic compositional variations in the Cape York iron meteorite. *Geochimica et Cosmochimica Acta* 46:1913–1920.

Goldstein J. I. and Short J. M. 1967. The iron meteorites, their thermal history and parent bodies. *Geochimica et Cosmochimica Acta* 31:1733–1770.

Kracher A., Kurat G., and Buchwald V. F. 1977. Cape York: The extraordinary mineralogy of an ordinary iron meteorite and its implication for the genesis of III AB irons. *Geochemical Journal* 11:207–217.

Nielsen H. P. and Buchwald V. F. 1982. Roaldite, a new nitride in iron meteorites. Proceedings, 12th Lunar and Planetary Science Conference. pp. 1343–1348.

Olsen E., Erlichman J., Bunch T. E., and Moore P. B. 1977. Buchwaldite, a new meteoritic phosphate mineral. *American Mineralogist* 62:362–364.

Pederson H. 2012. *Road-map to the Indian's Treasure*. *On the Chilean meteorite Vaca Muerta*. Norderstedt, Germany: Demand GmbH. 300 p. ISBN9788771144406.

Post J. E. and Buchwald V. F. 1991. Crystal structure refinement of akaganéite. *American Mineralogist* 76:272–277.

Schaudy R., Wasson J. T., and Buchwald V. F. 1972. The chemical classification of iron meteorites I. A reinvestigation of irons with Ge concentrations lower than 1 ppm. *Icarus* 17:174–192.

Scott E. R. D., Wasson J. T., and Buchwald V. F. 1973. The chemical classification of iron meteorites—VII. A reinvestigation of irons with Ge concentrations between 25 and 80 ppm. *Geochimica et Cosmochimica Acta* 37:1957–1976.