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Waldo Heliodoor Zagwijn (1928–2018): the instigator and architect of European chronostratigraphy

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Review

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Abstract

On 26 June 2018 Waldo Heliodoor Zagwijn died at the age of 89. He was an Emeritus Professor of the Faculty of Earth Sciences, Vrije Universiteit in Amsterdam. As a geologist, palynologist and palaeobotanist he focused on developing a stratigraphy of the Netherlands based on changes in vegetation and climate. The Dutch setting of a subsiding basin, and the clear signal of a sequence of glacial–interglacial cycles, was promising. As early as the late 1950s it became clear that the Quaternary Period included more than the previously assumed four ice ages in the Netherlands. In his PhD thesis Zagwijn defined the start of the Quaternary around 2.5 million years before the present (2.5 Ma). The international community accepted Zagwijn's arguments after he retired. He showed how the rivers Meuse, Scheldt and Rhine had built the Netherlands in four dimensions. He is the instigator and architect of the climate- and chronostratigraphy of the Quaternary Period of Western Europe.

Early education

Waldo Zagwijn was born on 16 October 1928 in The Hague. His father, a composer, had married when he was 50. Waldo's uncle was a music conductor but Waldo did not inherit the family's musical genes. His mother was much younger and had travelled a lot in her 20s, to Africa and elsewhere. Later, she worked as a telephone operator. She had a collection of minerals, and perhaps this interest explains Waldo's second name 'Heliodoor' (Al_2Be_3, a light-green mineral). Is it surprising that Waldo became a geologist?

Waldo attended the Haganum Gymnasium in The Hague where the well-known Dr Schierbeek taught biology. During the war he persuaded Waldo to spend a summer in the province of Limburg, where he collected fossils in the famous 'Heimansgroeve'. Waldo collected fossil seeds and fruits, and his interest in Earth sciences mushroomed. When Waldo left the gymnasium in 1947, studying geology was an obvious choice.

Academic education in Leiden

Waldo studied geology at Leiden University from 1947 to 1952. He was taught by professors Escher, Niggli, de Sitter, Van der Vlerk (geology), Florschütz (palaeobotany) and Lam (botany). He chose to study the Quaternary, a field of research in which his teachers Van der Vlerk and Florschütz had already achieved significant recognition. Florschütz did pioneering work in palynology in the 1930s and is considered the founding father of Dutch palynology. Later, Waldo Zagwijn played an important part in the application of palynology in applied geology, particularly in the 1950s and 1960s. Within five years, while also having a job teaching students the basics of palynology, Waldo finished his studies (July 1952). Florschütz and Van der Vlerk must have been inspiring teachers. Thomas van der Hammen writes in his obituary on Florschütz, 'Nearly three months before his death I received a letter from Van der Vlerk full of the same spirit as 25 years before. His mental capacity had in no way diminished and it seemed as if he had not aged' (modified after Van der Hammen, 1974).

Van der Vlerk and Florschütz published a very inspiring book *Nederland in het ijstijdvak; de geschiedenis van flora, fauna en klimaat, toen aap en mammoet ons land bewoonden* ('The Netherlands during the Ice Ages; history of flora, fauna and climate, when ape and mammoth lived in our country') (Van der Vlerk & Florschütz, 1950). The concepts explained in this book had a substantial influence on the development of Quaternary research in the Netherlands and on the education of a new generation of geo-ecologists, including Thomas van der Hammen and Waldo Zagwijn. Zagwijn took no interest in plants a priori, but he realised how this type of information could supplement regular geological information. Zagwijn became an all-round man early in his career. In 1952 he obtained his doctorate *summa cum laude* with geology, palaeontology and botany as the main subjects. Then, he joined the army.

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Development of pollen analysis

Between the two world wars, palynological research developed rapidly (Birks & Berglund, 2017), becoming an essential instrument in stratigraphical correlation and relative age determination. Based on a geological–palaeobotanical–palaeoecological context, Waldo was able to reconstruct the regional climate history. Subsequently he compared the climate history of the Netherlands to that of Western and Mediterranean Europe. He was interested in relatively warm intervals (interglacials and interstadials) for practical reasons. During warm intervals the Netherlands was covered by vegetation, leaving evidence (seeds, fruits, pollen) in the sediments (Fig. 1). The lack of this palaeobotanical evidence in glacial deposits leads to the conclusion that during the coldest phases of glacial periods, the Netherlands had hardly any vegetation cover. Zagwijn placed the changing patterns of vegetation in a four-dimensional time–space image and reconstructed the palaeogeographical evolution of Western Europe. In the Netherlands pollen analysis was applied in e.g. archaeology, palaeoclimatology and industry, and in many government-funded projects varying from geological mapping to infrastructural works.

A career at the Geological Survey

In April 1954 Waldo was employed at the Geological Survey. One of his first duties was to contribute several chapters of the *Geological History of the Netherlands*, edited by Pannekoek (1956), which served as an explanatory volume to the *Geological Map of the Netherlands* on the scale of 1:200,000 published by the Royal Netherlands Geological and Mining Society (KNGMG) and the Geological Survey (RGD). The contents of this volume gave an early glimpse of his future career, with his contributions on: continental Miocene, continental Pliocene, Praetiglian, Tiglian, Needian, stratigraphy and periglacial phenomena of the Tubantian, aeolian sands of the Tubantian, Older Holocene deeper peat, peat, and recent blown sand and inland dunes. Together with Jan Zonneveld he wrote one of his first papers on the complexity of the Cromerian (Zagwijn & Zonneveld, 1956). At the Geological Survey, he became head of the Department of Palaeobotany and Stratigraphy and was encouraged to study for a PhD. Professor Van der Vlerk, studying the Pleistocene of the Netherlands, was his supervisor. In contrast to older geological periods, defined on the basis of biostratigraphic evidence, Pleistocene stratigraphy was based on geomorphological evidence. The four Pleistocene ice ages of Western Europe (Günz, Mindel, Riss and Würm) had been defined on the evidence of moraines and river terraces using the terminology of Penck and Brückner (1901–1909).

While working on his thesis Zagwijn published papers showing that the classical subdivision of the Pleistocene was too simplistic (Zagwijn, 1956, 1957). In 1960 Zagwijn was awarded a PhD *summa cum laude* for his thesis 'Aspects of the Pliocene and early Pleistocene vegetation of the Netherlands'. He was the first to show that the Pleistocene included more than four ice ages (Fig. 2). In Waldo's thesis (Zagwijn, 1960) the warm period of the Tiglian was not addressed, as Florschütz had already reserved this period for his own studies. Later, Waldo also published a paper about the Tiglian (Zagwijn, 1963a) and a well-illustrated synthesis of his thesis for a wider audience (Zagwijn, 1963b).

Waldo married Reinske Sjoerds, a petrological laboratory technician at the Geological Survey. They had two sons, Peter (1965) and Erik (1968). Waldo was a well-organised man who worked full days at the Geological Survey but brought little work home.

Fig. 1. Waldo Zagwijn in his favourite surroundings, studying plant remains in the Belfeld Clay in a pit at Maalbeek, 1992 (after de Jong, 1995).

He had friendly contact with many colleagues, but maintained some distance as he liked his privacy.

Pollen analysis and palaeobotany were not the main objectives, but he used vegetation and climate history as a way to develop Quaternary stratigraphy. After Libby had discovered the radiocarbon-dating method Waldo immediately applied it and was able to date his earlier-published 'Amersfoort' interstadial at 64,000 years BP (uncalibrated) (Zagwijn, 1961). The Geological Survey focused on geological mapping and applied geology but the relevance of using palaeobotany and palynology as a scientific instrument was well-recognised. Zagwijn was often out in the field, particularly in the area around Reuver and Tegelen in the Southeastern Netherlands, near the Dutch–German border (see also Westerhoff, 2009). He was in close contact with survey geologists in Krefeld, Nordrhein-Westphalia. At this time, the opencast lignite mines in the Lower Rhine Embayment were opened and steadily excavated to a depth of 400 m. Well-developed lowland sequences of Miocene, Pliocene and Pleistocene deposits were exposed there and the stratigraphy could be studied to new levels of detail. Later in his career Zagwijn also included the Holocene period in his studies.

Conceptual contributions to the start of the Quaternary

Zagwijn was much involved in the definition of the base of the Pleistocene. In 1957 he had already argued that the Pleistocene should start at the moment when thermophilous trees began to disappear from the European flora: this was during the cold period of the Pretiglian (Zagwijn, 1957). He showed that climate cycles had also occurred in previous periods of the Pliocene but with less impact on Western European vegetation.

Zagwijn had expanded his terrestrial chronostratigraphy with sequences in Belgium (Zagwijn & Paepe, 1968; Paepe & Zagwijn, 1972), Germany (Zagwijn & Menke, 1971) and France

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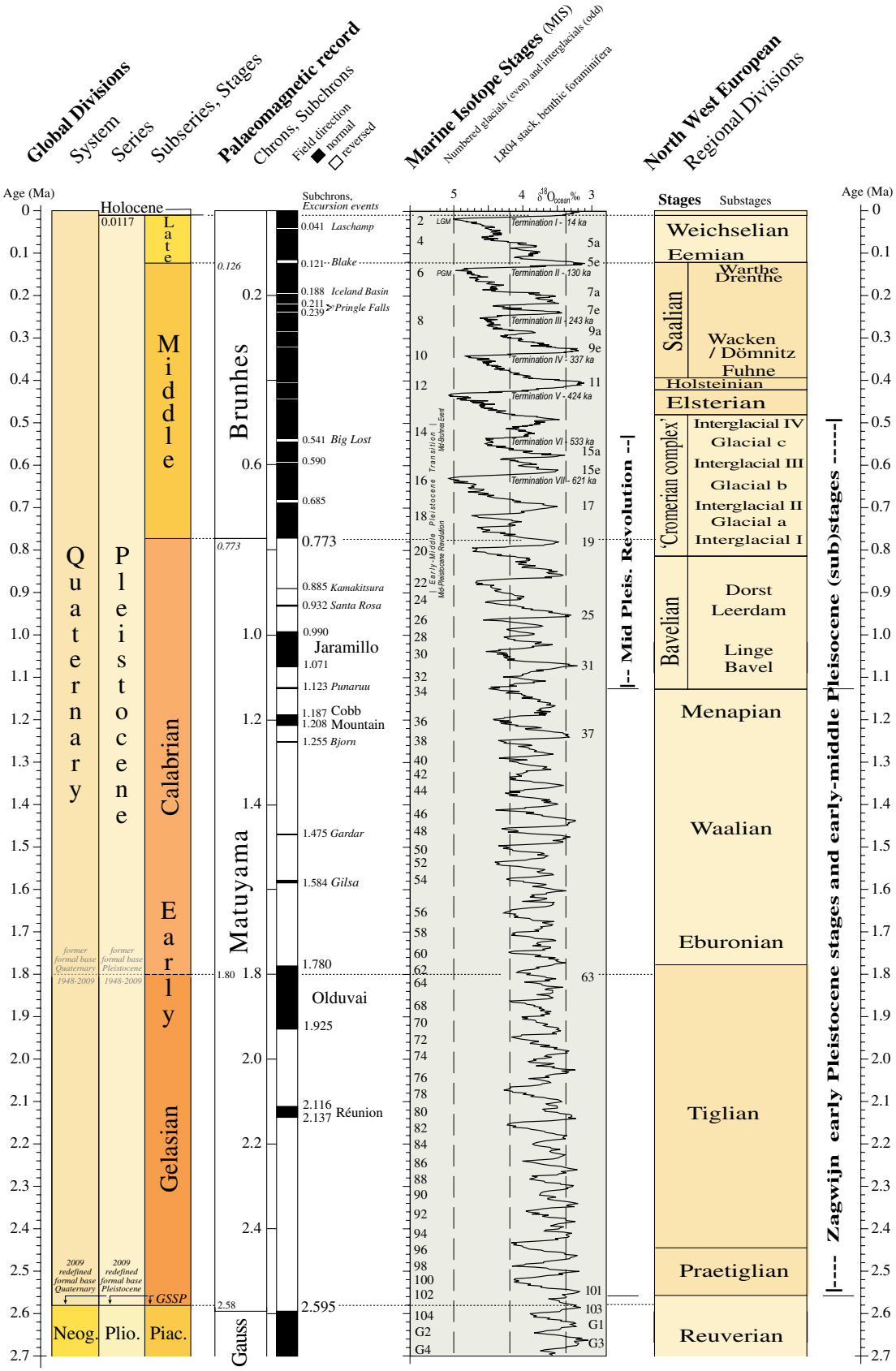

Fig. 2. The early and middle Pleistocene division nomenclature developed by Zagwijn (after Cohen & Gibbard 2019). Courtesy of K. Cohen.

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(Suc & Zagwijn, 1983; Zagwijn & Suc, 1984) and found the climate cycles largely corresponded with oscillations in the marine oxygen isotope record. While more and more $\delta^{18}O$ records had been constructed from long marine sediment cores, the marine $\delta^{18}O$ record such as the V28-239 record of Shackleton & Opdyke (1976) had grown into a detailed record of global significance. In contrast, Zagwijn had to study short sediment cores and exposed profiles from many different locations, and his job was to complete a difficult jigsaw puzzle. His locations were close to the expansions of the glacial ice sheets, and the sedimentary archive had either partially been eroded or was no longer *in situ*. All the parts of the puzzle showed short and incomplete intervals of the Quaternary. In Western Europe the first long and continuous sedimentary archive covering a full glacial–interglacial cycle is found in northern France (Woillard & Mook, 1982). Zagwijn's ability to deal with a four-dimensional dataset allowed him to build a solid chronostratigraphical framework from many short intervals and from a suite of locations. His encyclopaedic knowledge of the details of many published pollen records was very helpful. There is an interesting correspondence with Nick Shackleton who also remembered the details of many $\delta^{18}O$ records. In discussions after congress presentations Zagwijn showed his erudition by knowing the evidence; discussions were always sharp, with much content, but sympathetic.

In the 1970s, discussions focused on the number and intensity of Pleistocene glaciations affecting Northwest Europe (de Jong, 1988). A paper in collaboration with English colleagues Phil Gibbard and Richard West well reflects the state of knowledge at the end of the 1980s (Gibbard et al., 1991). Marine geologists preferred to place the start of the Pleistocene at *c*.1.77 Ma, close to the start of the Olduvai palaeomagnetic subchron. However, considering climate, landscape and biotic evolution on the continents, changes in conditions around 1.77 Ma had little significance. Zagwijn saw the earlier slotted Pretiglian interval as the time when thermophilous trees disappeared from the Western European flora – more strongly than in Pliocene climate fluctuations before. The east–west orientation of European mountains (Alps, Pyrenees), and the southward expansion of the Scandinavian ice sheet that squeezed the latitudinally organised European vegetation zones, was leaving powerful evidence in the sedimentary archive in this part of the world, whereas in other parts of continents conditions and outcomes were different. Therefore, using 'a first ice age' to explain changing biogeographical patterns may be misleading. This process of migrating vegetation zones is well illustrated in the chapter 'The floral record of the late Cenozoic of Europe' (Van der Hammen et al., 1971), a classic paper still frequently cited.

Zagwijn used palaeobotanic evidence and its implications to build a chronostratigraphic framework. Every time he found the Pretiglian to be the logical start of the Quaternary period (Zagwijn, 1963a, 1974a, 1975a, 1982, 1985, 1992). Zagwijn defined several warm interglacials and interstadials and named them. On the basis of regional vegetation reconstructions he showed that up to one million years ago, glacial refugia of thermophilous trees were relatively close to the Netherlands (Central France and Southern Germany), whereas during the last million years these were further away (near the Alps and Mediteranean shores). In terms of palynologically inferred temperature fluctuations, there was good correlation with the ocean-averaged marine $\delta^{18}O$ record (e.g. the LR04 stack of Lisiecky & Raymo, 2005) that showed similar differences in intensity before and after *c*.1 Ma, a change dubbed 'the mid-Pleistocene revolution' (e.g. Head & Gibbard, 2005). The early and middle Pleistocene division nomenclature developed by Zagwijn is still used today (Fig. 2 after Cohen & Gibbard, 2019).

Serving geological mapping of the Netherlands, Zagwijn was involved in the lithostratigraphical division and nomenclature of the Dutch Quaternary (Zagwijn & Van Staalduinen, 1975). In the pre-Quaternary period Zagwijn had recognised several less significant cool intervals, such as the Reuverian. Based on the presence of thermophilous trees such as *Carya*, *Pterocarya* and *Tsuga*, Zagwijn defined the Eburonian glacial, the Waalian interglacial and the Menapian glacial periods (Zagwijn, 1957, 1960). Based on the same arboreal taxa, he argued that the early–middle Pleistocene transition should be placed between the Menapian and the Cromerian Complex. He studied the interglacial Bavelian Complex, chronostratigraphically positioned between the Menapian and the Cromerian Complex (Zagwijn et al., 1971), and marking the end of the early Pleistocene, with Jan de Jong (Zagwijn & de Jong, 1984). He worked on the Holsteinian and Saalian organic beds in the Middle Pleistocene (de Ridder & Zagwijn, 1962; Zagwijn, 1973, 1978). For the Eemian of the Netherlands, he published a sea-level record (Zagwijn, 1983, 1996). In the late Pleistocene Zagwijn studied the Amersfoort, Hengelo and Moershoofd interstadials (Zagwijn, 1961, 1974b, 1989a; van der Hammen et al., 1967). Towards the end of his career he studied the Eemian and Holocene interglacials, using marker taxa to build consistent climate reconstructions (Zagwijn, 1994, 1996). Together with Saskia Jelgersma, Jan de Jong and the physical geographer Jean François van Regteren Altena, Zagwijn studied the coastal dunes in profiles several kilometres long near IJmuiden, along the Noordzeekanaal and in the Waterleidingduinen (dune area with infiltration basins to produce drinking water for Amsterdam). They identified the so-called Old Dunes and Young Dunes between the villages of Bergen and Monster. Radiocarbon-dated soil horizons reflected alternating dry and wet periods. The authors show an increasing human impact on the dune area since the late Middle Ages. These studies contributed to understanding of the geology, archaeology and vegetation history of the coastal dune landscape (Zagwijn, 1965, 1969, 1971, 1984; Jelgersma et al., 1970; van der Maarel & Zagwijn, 1971). This understanding aggregated in the monumental series of books *Wilde Planten; flora en vegetatie in onze natuurgebieden* ('Wild plants, flora and vegetation of our nature reserves') (Westhoff et al., 1971) in which Zagwijn showed how the present-day surface of the Netherlands is related to the complex structure of the subsurface.

The Geological Survey was mapping the North Sea basin, mainly for aggregates and other mineral resources; however, for Zagwijn the North Sea basin sediments were of importance in developing palaeomagnetic records. After the start of the Pleistocene had been defined (Zagwijn, 1960), palaeomagnetism showed 2.3 million years to be the base of the Quaternary (Van Montfrans, 1971). Where Zagwijn placed the start of the Pleistocene in the North Sea basin, sediment accumulation increased tenfold. Tectonic uplift of the hinterland was a possible explanation; however, according to Zagwijn, the increasing amplitude of climate fluctuations from the Pretiglian onwards (2.56–2.44 Ma) meant that Western Europe was mostly north of the forest line during much of a glacial period, and forest was gradually replaced by steppe, tundra and polar deserts. With the help of palaeomagnetic records Zagwijn and Suc (Montpellier) found a reliable correlation between the chronostratigraphies of Western Europe and the Mediterranean area (Suc & Zagwijn, 1983; Zagwijn & Suc, 1984).

The start of the Quaternary period has long been discussed. Arguments from marine geology (a start at 1.77 Ma) long prevailed over compelling evidence from the continents (a start at *c*. 2.6 Ma). In a summary at the end of his career, Zagwijn again argued for a

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start around 2.3 Ma (Zagwijn, 1992); as he was nearing retirement he could make a definite statement: *'Despite recent attempts, in particular by marine palaeontologists, to minimize the status of the Quaternary and even to deny it a place of its own in the stratigraphic scale, the present author is of the opinion that the exceptional climatic evolution that the planet Earth has witnessed in its latest history and which resulted in repeated large-scale glaciation in the northern hemisphere, is a sufficiently valid criterion to assign this interval a status of its own on the Period level.'* When he was 82 the International Commission on Stratigraphy of the International Union of Geological Sciences (IUGS-ICS) formalised the redefinition of the start of the Pleistocene at *c*.2.58 Ma (Gibbard et al., 2010). This was not only a recognition of the concept published in Zagwijn's 1960 thesis, but also a plea for a more prominent role of climate swings, also reflected in long palynological records, in the stratigraphy of the Quaternary (Suc et al., 2018). Zagwijn did not see this acceptance as a personal victory; he had his own reasons for placing the start of the Pleistocene around 2.3 Ma, and he knew that other criteria are used in other regions. Zagwijn was too much of a scientist to be excited by other colleagues accepting or not his arguments.

Palaeogeographical maps

Probably during two glacial periods of the Pleistocene only, the northern part of the Netherlands was covered by ice. This caused the courses of the rivers Meuse, Scheldt and Rhine to change repeatedly. Zagwijn drew maps and showed in a spatial–temporal framework how the Netherlands were shaped during successive stages of the Quaternary (Zagwijn, 1974c, 1975b, 1979, 1989b; Van Staalduinen et al., 1979) and he became well known for his popular scientific palaeogeographical maps of the Netherlands, showing how the Low Countries got their shape over Pleistocene and Holocene times (Zagwijn, 1986). At the turn of the twenty-first century, palaeogeographical understanding of the Netherlands continued to expand, partly inspired by the work of Waldo Zagwijn (e.g. Berendsen & Stouthamer, 2001; Busschers, 2008; Westerhoff, 2009; Peeters et al., 2016). The set of 12 palaeogeographical maps in the *Atlas van Nederland in het Holoceen* (Vos et al., 2011) and updated versions (Vos & De Vries, 2013) show the impressive detail currently reached for different parts of the Netherlands – owing to continued data collection and computerised data combination (Hoek, 1997b; Van der Meulen et al., 2013; Pierik et al., 2016; Cohen et al., 2017a,b; Woolderink et al., 2019) as well as to the inspiration of Zagwijn's palaeogeographical legacy (Berendsen & Stouthamer, 2001; Westerhoff, 2009; Vos, 2015).

Zagwijn's expertise was frequently consulted

Zagwijn's research was key to palaeobotany, geology, climatology, physics and soil science coming together. Florschütz (1887–1965) had developed the foundations and contacts between academia, industry, museums and governmental organisations. Zagwijn expanded this field using new methods (C14-dating, palaeomagnetism) and new proxies. His personal archive contains much correspondence with colleagues from institutes representing many disciplines such as geology, oceanography, anthropology, archaeology, botany, zoology and palynology. Correspondence with governmental offices also increased substantially: foreign geological surveys and biostratigraphical companies. In the Netherlands Zagwijn was consulted by governmental offices about drinking-water, the establishment of polders in the IJsselmeer, the construction of canals in Twente, and by the Directorate-General for Public Works and Water Management (Rijkswaterstaat) for coastal protection. Many of his colleagues were well trained in thinking long-term. Robert C. Bright from the University of Minnesota wrote to Saskia Jelgersma – in a letter forwarded to Zagwijn because he was a member of the Netherlands' Radiocarbon Dating Commission – on results of the samples he had submitted: his letter starts 'It seems like a million years ago when we had a short meeting in Boulder . . . '

Zagwijn's archive is an impressive source of information and it shows he was frequently consulted by colleagues about the interpretation of new data. Although time-consuming, it contributed to an ever-improving understanding of the climate stratigraphy of Western Europe. It is hardly surprising that he was often asked to contribute to national and international commissions; to name but a few: the IUGS-ICS Subcommission for Stratigraphic Classification; the INQUA (International Union for Quaternary Research) Subcommission on the Pleistocene of Europe (1967–1993); the Scientific Committee UNESCO–IUGS International Geological Correlation Programme (1976–1981); the Commission for Biosociology and Palaeobotany of the Royal Netherlands Botanical Society (1958–1961); the Foundation for Isotope Geological Research (1970–1985); the ministerial Advisory Commission of Natural History Museums (1981–1993); and the section Earth Sciences of the Royal Netherlands Academy of Sciences (1986–1993). His contributions to the INQUA were fundamental. He was a member, later chairman, of the INQUA-Netherlands Commission (1963–1993), and a member of the INQUA Commission for the Palaeogeographic Atlas of the Quaternary.

Zagwijn was a member of the editorial boards of *Review of Palaeobotany and Palynology* (1966–1971), *Géologie Méditerranéenne* (1975–1993), *Bulletín de l'Association Française pour l'Etude du Quaternaire* (1980–1993), *Acta Palynologica* (1989–1993) and *Quaternary International* (1989–1993); he was also an external examiner of PhD committees in the Netherlands and France.

Both Zagwijn and Van der Hammen were involved in the famous Climate/Long Range Investigation Mapping and Predictions Project (CLIMAP) of the US National Science Foundation. In 1974, in Amsterdam, they organised a workshop entitled 'The climate record of the last million years', in which top international scientists were involved. The results of the CLIMAP project were cited for decades, showing that the understanding of this group of scientists was far ahead of general societal perception of the impact of climate change.

International recognition

For a long time Zagwijn was active in the German Quaternary Association (DEUQUA) and he received the Albrecht Penck Medal in 1972. In 1974, Zagwijn and Van der Hammen received the Van Waterschoot van der Gracht Medal of the Royal Geological and Mining Society of the Netherlands (KNGMG). In 1980, Zagwijn was appointed a member of the Royal Netherlands Academy of Sciences (KNAW) and in 1983 he was appointed *Officier in de Orde van Oranje Nassau* by the queen. He was elected an Honorary Life Fellow of INQUA in 1987, and an Honorary Member of the Quaternary Research Association in 1994.

Professor at Vrije Universiteit Amsterdam

In 1989 Zagwijn was appointed Professor of 'Quaternary Palynology' at Vrije Universiteit in Amsterdam (Fig. 3). He was

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Fig. 3. Waldo Zagwijn interviewed on the occasion of his appointment at Vrije Universiteit Amsterdam in 1989. Courtesy of mrs. R. Zagwijn-Sjoerds and collection photo press agency De Boer, Haarlem.

proud of this move so near the end of his career and held his inaugural lecture on Interglacials (Zagwijn, 1991a). His teaching as professor included a fascinating series of lectures on the Quaternary vegetation history of Europe (Zagwijn, 1991b). His unprecedented knowledge of the evidence was obvious and it became clear why he was the person who had completed the climate stratigraphical jigsaw puzzle. As there was only a short time before his retirement Zagwijn supervised only one PhD student, Wim Hoek, who got his PhD with the thesis 'Palaeogeography of Lateglacial vegetations' (Hoek, 1997a,b). This subject had developed in the 1970s but Zagwijn himself was unable to compile that much data; he had to wait for this unique opportunity. The Lateglacial, though, was a period which he investigated for his very first scientific publication (Zagwijn, 1952).

As well as teaching at Vrije Universiteit for one day a week, Zagwijn was involved in developing the new building for the Geological Survey. Hindered by delays in the building process, Zagwijn presented his inaugural lecture, entitled *Interglacialen* ('Interglacials') on 20 March 1991 (Zagwijn, 1991a). The new building was opened in 1992, coinciding with Zagwijn's retirement from the Geological Survey, but he worked a further year at the university to finish several projects. During his four years of professorship Zagwijn developed climate reconstructions of the last two interglacial periods, the Eemian and Holocene (Zagwijn 1994, 1996).

Professor Zagwijn as an Emeritus

In 1993, on the occasion of Zagwijn's retirement from Vrije Universiteit in Amsterdam, an international symposium was organised in the Royal Academy of Sciences building. In a special issue of *Mededelingen van de Rijks Geologische Dienst*, entitled *Neogene and Quaternary Geology of North-West Europe; Contribution on the occasion of Waldo H. Zagwijn's retirement*, 34 papers written by 67 of his colleagues were published (Herngreen & Van der Valk, 1995). This special issue also includes a list of the almost 100 publications by Zagwijn (De Jong, 1995).

Zagwijn had decided to end his scientific work after retirement. He devoted his time to his family, to travelling and to his hobbies. In 2004 he was hospitalised and needed a period of convalescence. About ten years after this his mental health deteriorated and he spent his last year in a nursing home, where he died. Zagwijn was cremated after a funeral with only family members present.

We remember Waldo Zagwijn as an eminent, erudite and modest scientist with a fabulous memory for detail. He had a remarkable ability to develop an image in time and space of the Netherlands below the surface. He developed early understanding of the Pliocene and Quaternary palaeogeographical, geological and climatological developments of Western Europe, and the Netherlands in particular. He is the instigator and architect of the chrono- and climate stratigraphy of Western Europe.

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