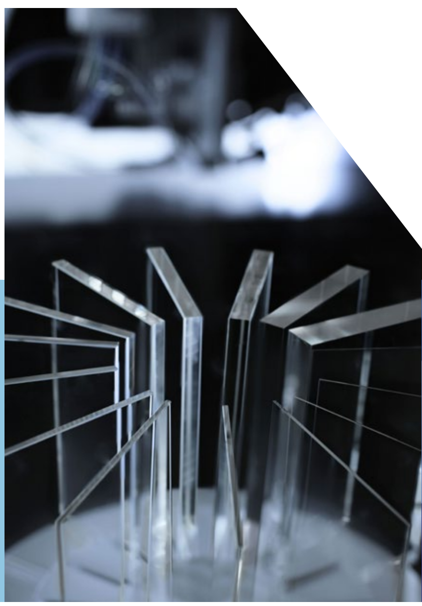
Schott at the Sharp Edge

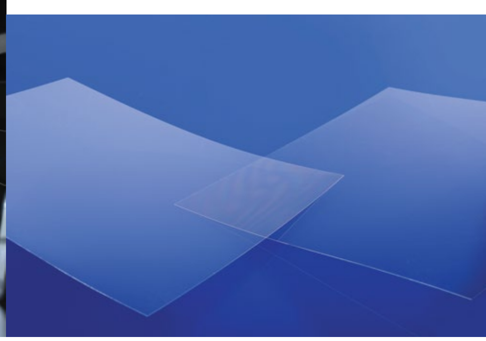
Precision glass and glass-ceramics influence signal strength

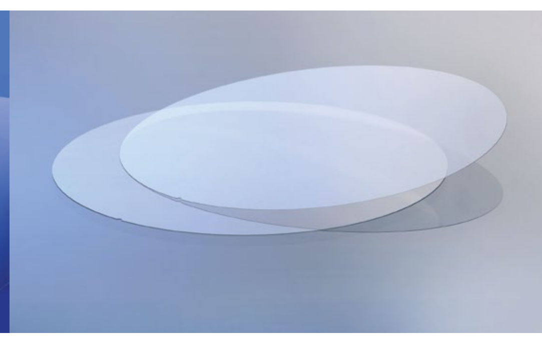
Today's geospatial reality involves a world awash with sensors. As developers seek to embed lidar technology in ever smaller, increasingly mobile installations, the importance of sensor encasement grows.

None of this is new to German glass manufacturer Schott, which is part of the Carl Zeiss Stiftung, the foundation that includes also the famous Carl Zeiss company.

Headquartered in Mainz, Germany, Schott AG specializes in the manufacture of glass and glass-ceramics. The company employs over 16,000 people in 34 countries, almost 40% of them in Germany. In 2019 it reported annual revenues of €2.2b, of which 87% was generated outside Germany. Schott is well known in the geospatial community, because its glass has been widely used in lenses for surveying and photogrammetric instruments. Publisher Allen Cheves and managing editor Stewart Walker, therefore, were delighted to receive an invitation to visit the Schott facility, a few kilometers from the spot where Johannes







BY ALLEN **CHEVES** & DR. A. STEWART **WALKER**

Schott's headquarters in Mainz, Germany, established in 1952 after the business was moved from Jena after World War II.

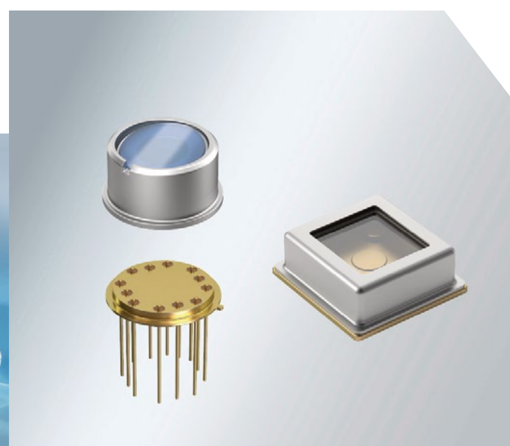
Gutenberg's movable-type printing press revolutionized the transmission of knowledge some 580 years prior.

Schott headquarters in Mainz

Our hosts were Christine Fuhr, innovation/technology communications manager, entering her 30th year with Schott, and Jonas Spitra, manager corporate and innovation communication. On entering the building, we admired the huge stained-glass window, lit by the morning sun. We enjoyed a guided tour of the remarkable museum, marveling at the range of glass and glass-ceramic products created by the company since its foundation. Indeed, "museum" isn't quite the right word, as the extensive space includes superb displays of the latest Schott products and concepts. The innovation and ingenuity of Schott's top-class engineers have clearly endured throughout the company's more than 135-year history. We saw amazing technologies, such as glass with almost zero thermal expansion, glass that can be bent and folded, and fiber optics. We marveled at the application areas, which Schott categorizes as home appliances, life sciences, astronomy, pharma, electronics and automotive.

The various technical developments for which Schott is renowned are too numerous to describe here, but there's a fine list on the website[1]. While most

1 *https://www.us.schott.com/english/company/corporate_history/milestones.html#block166818*



LIDAR Magazine readers are focused primarily on the geospatial, Schott's glass products are used in a myriad of applications. Kitchen stove tops, for example, are a gigantic market. There are, of course, other high-quality optical glass manufacturers, but products such as Schott's BK7 (now N-BK7) are recognized by almost anyone in the optical industry. Hexagon Geosystems, for example, uses BK7/N-BK7 in important components of several of its systems, for example optical windows. When it comes to focal optics, the designers have a large number of glass types to choose from. They use glass with specific characteristics for each individual lens in a system, balancing optical and mechanical characteristics with the particular prescription desired for the element to produce an optimal overall design. Companies such as Schott target specific characteristics, for example, transmission wavelength range, scattering and refractive index (among many others), in order to offer products that can ultimately be employed across the widest possible range of optical devices.

Enter lidar

Schott is interested in lidar. To learn more about Schott's lidar strategy and positions, we were joined for lunch by Boris Eichhorn, senior manager new ventures. Coming to Schott from Siemens in 2017, he had worked on Schott's initiatives in augmented reality before specializing in lidar. He explained that Schott has built a growth platform, which causes customers and prospective customers to come to the company, looking for solutions. Schott can play a proactive consultancy role, i.e. go beyond being a materials supplier. He mentioned glass solutions for protective windows as well as the optical paths and hermetic packaging for laser diodes, MEMS mirrors and photo diodes. As a result of its development path, Schott is able to occupy different positions in the value chains of companies,whether they are component and sensor providers, system integrators or tier 1s.

According to a market study by Yole Développement of Lyon, France, 70% of the lidar market will be automotive by 2025, characterized by high volume and low price[2]. Schott is extremely willing to become involved in lidar and can contribute a great deal in terms of materials and components, which Boris summarized in the message, "Glass, glass-ceramic, and glass-to-metal sealed components protect lidar sensors, while maintaining a high optical performance". This includes protective windows; filters, mirror substrates and lenses for the optical path; and hermetic packaging for harsh conditions. Schott explains much of this on its website, with a focus on automotive applications, though the company's interest extends beyond AVs to robotics and many other applications related to geological and industrial uses. In order to reach the mass market, however, manufacturers need components that meet exact performance standards economically.

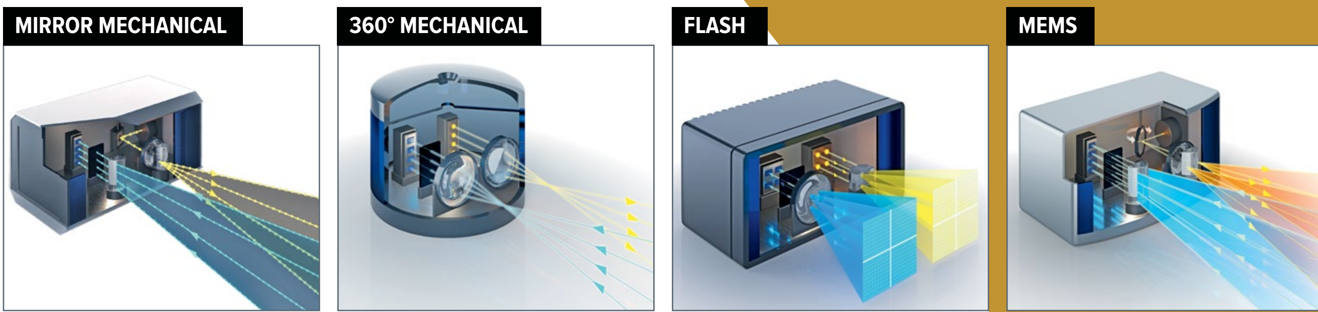
Boris Eichhorn, managing Schott's charge into lidar

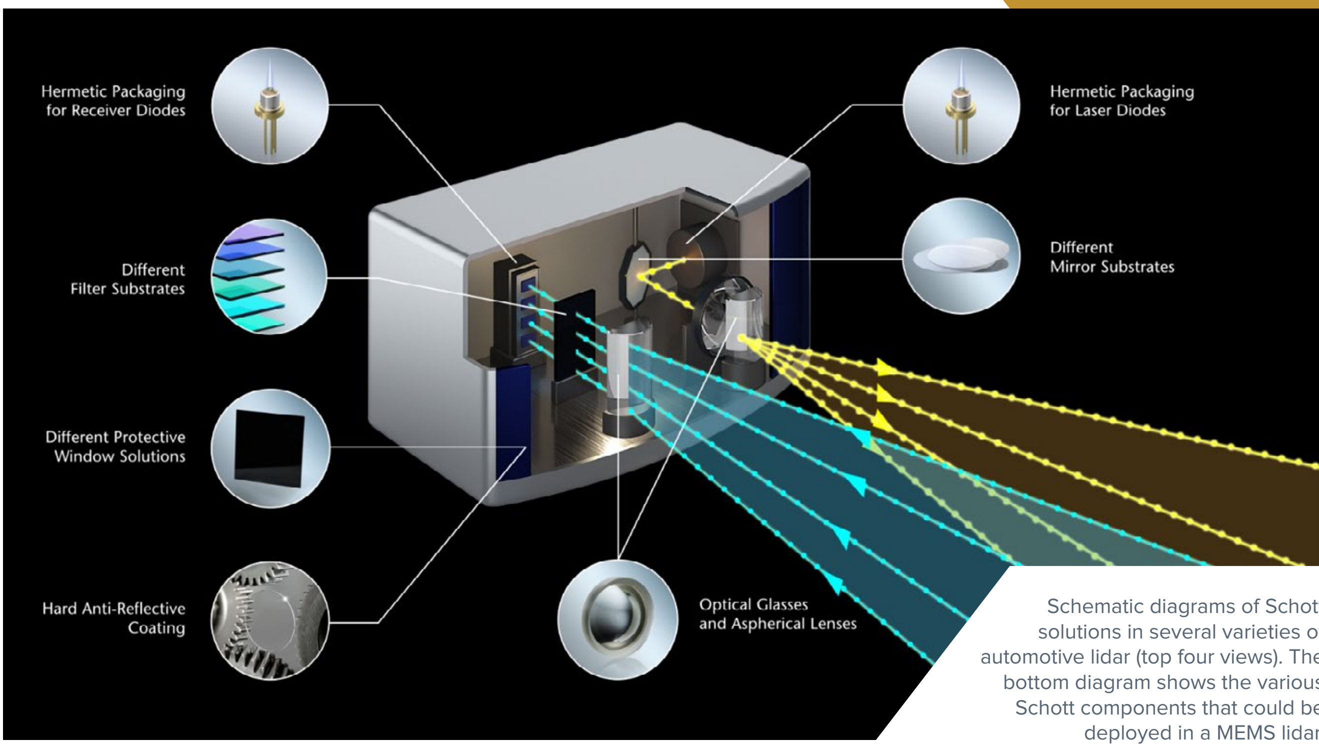
> "Glass, glass-ceramic, and glass-to-metal sealed components protect lidar sensors, while maintaining a high optical performance."

High-quality protective windows must be tough to withstand unforgiving conditions. A lidar sensor has to function reliably at a high level to provide a continuous situational picture, so it needs protection from rain, temperature fluctuations and impacts from stones and other debris. Protective windows, moreover, must feature high transmission at lidar wavelengths that allows near infrared (NIR) to pass through, while attenuating visible ambient light.

For the optical path of a lidar system, filters, substrates and lenses must provide high performance. The precision of the interacting components is key, because the laser beam cannot afford any loss of photons. Lidar sensors must deliver long-lasting, high image quality regardless of temperature differences or aggressive climate conditions. High transmission and an athermal lens

2 *http://www.yole.fr/Lidar_Market_Status.aspx*





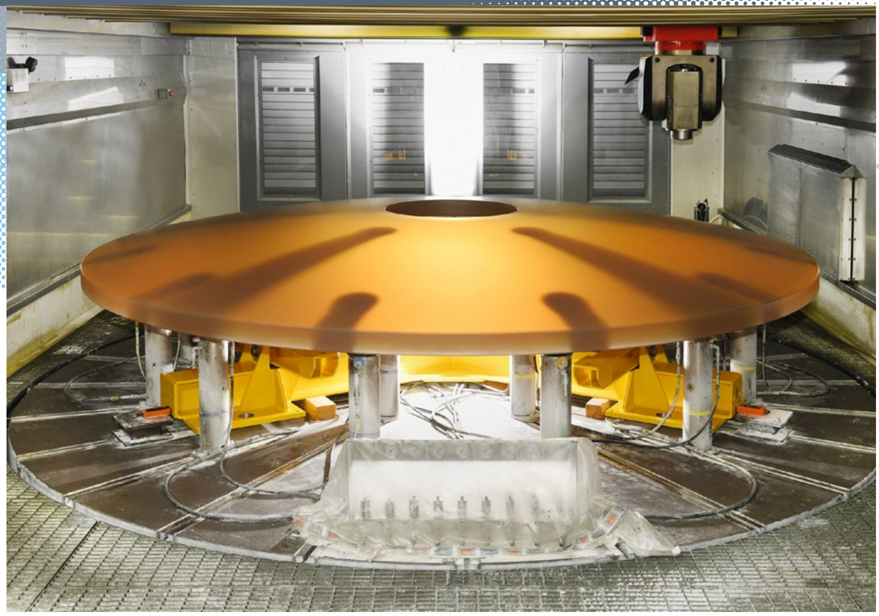
Schematic diagrams of Schott solutions in several varieties of automotive lidar (top four views). The bottom diagram shows the various Schott components that could be deployed in a MEMS lidar.

system design are typically taken into account. Overall, lidar sensors require superior imaging quality, while they must be compact and lightweight.

Hermetic packages protect and power lidar sensors to withstand demanding conditions like vibrations, shock, dust, moisture and extreme temperatures. The use of the best suited glass, for example, could ameliorate some of the problems lidar experiences in conditions such as snow and ice. Laser diodes, photo diodes and MEMS mirrors must be protected against internal condensation and challenging external elements of the driving environment in all types of lidar sensor devices. Schott believes that professional support and consulting is needed when it comes to product size, shape, materials, technology, and all-round R&D support as well as solutions optimized for competitive, high-volume manufacturing.

BOROFLOAT®33, a technical float glass from Schott, is gaining traction in lidar applications because of its excellent material properties at reasonable prices. The component quality has a tremendous impact on system performance.

Used as an entrance window, BOROFLOAT provides extremely high light transmission while remaining strong, lightweight, and resistant to potential corrosive environments or thermal changes. High transmission at the relevant laser wavelength is especially important as it ensures that light passes unimpeded through the entrance window, which serves as a protective cover for the components inside. If the entrance window impairs the lidar signal, it will not see its surroundings accurately. BOROFLOAT's high transmission properties stem from the use of extremely pure raw materials. It features greater than 92% light transmittance in the NIR wavelength range, outstanding colorless visual appearance, low auto-fluorescence, high resistance to solarization, and a low refractive index. BOROFLOAT also has a very strong microstructure, resulting in high material hardness, excellent abrasion resistance, and low degradation behavior during high-intensity radiation exposure.



Fabrication of the 4.25 m diameter secondary mirror for the Extremely Large Telescope, the centerpiece of the European Southern Observatory in Chile. The material used was ZERODUR, which has proved efficacious in Schott's astronomy market.

Lidar systems use lasers of a specific wavelength, typically 905 or 1550 nm. BOROFLOAT has a long history as a substrate for narrow bandpass filters that reduce signal-to-noise ratio, allowing only the wavelength of interest to be transmitted or received. BOROFLOAT glass is often the substrate of choice for such coatings, as a high material transmission is key for exceptional filter properties.

The Schott Story

Otto Schott, 1851-1936, photographed here in 1884

The Carl Zeiss company earned a reputation across Europe for its microscopes, but these were hard to make, so in 1866 Zeiss recruited university physicist Dr. Ernst Abbe, who developed optical theories that revolutionized the manufacture of lenses. Abbe joined Zeiss as a partner in 1875.

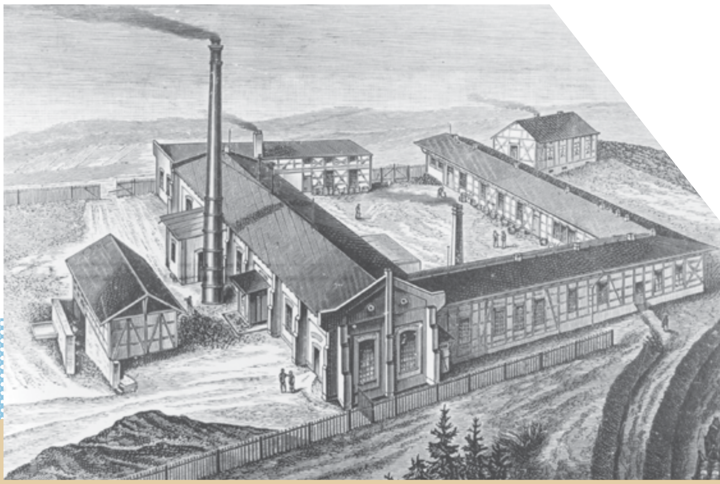
Otto Schott was born in Witten in Westphalia in 1851. As a young boy, he was fascinated by his father's glassmaking business and so enthusiastic about the family tradition of glassmaking that he studied chemistry, mineralogy and physics in Aachen, Würzburg and Leipzig. In 1875, he wrote a dissertation, "Contributions to the theory and practice of glass fabrication", in Jena. In 1879 he began basic research on the melting, glass-forming and crystallization behavior of many different chemical compounds. In 1882, he moved to Jena to facilitate a collaboration with Abbe and Zeiss. Two years later, these three, together with Roderich Zeiss, founded the Schott & Associates Glass Technology Laboratory. The Schott Villa, on Otto Schott Strasse in Jena, is open to the public, so visitors can see where he lived and worked as well as interesting exhibits. Schott developed specialized glasses with precisely defined properties for a wide variety of applications and turned his laboratory into an industrial company of international stature. With the development of entirely new types of glass and new production methods, Schott not only became the founder of modern glass science and glass technology, but also of the specialized glass industry.

Photogrammetrists know Abbe for his contributions later in his life, such as his comparator principle and his work with Carl

Another interesting option, currently in testing for use in lidar applications, is the versatile glass ceramic NEXTREMA®: although its light transmission might not be as outstanding as BOROFLOAT, NEXTREMA shows strength in impact and thermal shock resistance.

Geospatial reflections on Schott's history

We've put Schott's history into a sidebar on this page and the previous one, but here we pause to reflect on Schott's role in geospatial products. Carl Zeiss was born in 1816 and set up his workshop in Jena in 1846, to make laboratory equipment for the local university. Kern & Co. in Aarau had been founded in 1819, i.e. it had also preceded Schott. Kern began with the manufacture of drawing instruments but quickly moved into surveying equipment. Founder Jakob Kern's sons, Adolf and Emil, joined the business in 1857 and Jakob retired in 1863. Heinrich Wild, on the other hand, was born in 1877. He was chief engineer for geodetic instruments at Carl Zeiss in Jena from 1907 until



Schott & Associates Glass Technology Laboratory, founded in Jena in 1884

The Schott factory in Jena, seen here in a 1925 painting

Pulfrich on stereoscopic instrumentation, but he found fame also as a social reformer. In 1889, the year after the death of Carl Zeiss, Abbe, with the help of Schott, founded the Carl Zeiss Stiftung, initially to provide corporate benefits that were way beyond their time. Two years later, the glassworks in Jena become a foundation-owned enterprise. The Carl Zeiss Stiftung is now the sole shareholder in both Schott AG and Carl Zeiss AG. It uses dividends from its member firms to support research. By 1900, 50% of Schott revenue accrued from exports and in the period 1927-30 the first subsidiaries were set up. Otto's son, Erich, born in 1891, entered the business in 1917 after his older brother, Rolf, was killed in World War I. Erich took over the running of the business in 1928, eight years before the death of his father. After World War II, the American occupying forces orchestrated the "odyssey of 41 glassmakers", whereby selected management and experts were moved from Jena to West Germany. Key Carl Zeiss employees were also moved to the west in the same operation. The factory in Jena was now in the Soviet-occupied zone and became a

The Schott Villa in Jena, where visitors can see where Otto Schott lived and worked

state-owned company. The Schott group re-established itself in Mainz, under Erich's direction, in 1952. When the first of two Bauhaus-style buildings was completed, it established its headquarters there. Erich lived in one of these buildings and introduced the tradition of giving presents to employees working on Christmas day. There followed gradual expansion as Schott grew into a multinational group, starting with production in Brazil in 1954. In 1989, the year Erich died, the Otto Schott Research Center was set up in Mainz. With the reunification of Germany, the Mainz headquarters assumed management of and integrated the old plant in Jena. In 2004, legal steps were taken to convert the foundation enterprise to the corporation Schott AG. Its sole shareholder is the Carl Zeiss Stiftung.

1921. He returned to Switzerland after World War I and founded Wild Heerbrugg. In the chronology, therefore, Schott, founded in 1884, came after Carl Zeiss and Kern, but before Wild Heerbrugg.

Schott glass, naturally, was used in Carl Zeiss instruments and, in due course, in the big lenses required by aerial film cameras. Carl Zeiss, however, was not the only supplier of photogrammetric equipment to purchase all its glass from Schott. Wild Heerbrugg, which evolved into Wild Leitz, Leica, Leica Geosystems and Hexagon Geosystems, also used Schott glass for its aerial cameras for decades, both the RC film models and the ADS digital series introduced in 2000[3]. The reason was that all big Wild lenses for photogrammetry were "braune Optik". 'Braun' was not meant politically but 'schmelzenabhängig' (dependent on the melt). Normally the refractive index n of glass is specified with a tolerance of 100 points where 1 point corresponds to $\delta(n) = 10^{-5}$. The big glass blocks for the UAGS lenses, however, needed tolerance values of 50 or 30 points, a requirement which only Schott was able to meet. They had to select the glass carefully and measure the optical data at five different positions with the accuracy the designers needed. So each objective had its unique glass components and, to avoid a wrong mixing in the factory, they were always packed in brown paper! Braune Optik is still needed today for lenses where achromacy is important rather than resolution: resolution is handled by aspheres, but "color" needs different glasses. High-end optics needs glass material with a high refractive index near to 2, which traditionally was only possible using lead and arsenic as chemical components. When about 2000 'green' glasses, i.e. free of lead and arsenic, were requested, Schott had to redesign its whole glass spectrum of more than 200 glasses, a complicated and very expensive transformation. In close cooperation with its main industry partners, Leica, Carl Zeiss, Schneider Kreuznach and Rodenstock, however, the glass spectrum could be reduced to about 100 types, a win/win situation for all parties. Remember also that geospatial system suppliers purchase optical components from specialist vendors, according to make-or-buy decisions; these may source their glass from Schott. Vexcel Imaging, for example, makes use of Schott glass in its UltraCam aerial cameras through the purchase of lenses from the Qioptiq Photonics[4].

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Endnote

We were privileged indeed to visit a leading world glass manufacturer and innovator with almost 140 years of experience and the most distinguished history. Much of Schott's involvement in our geospatial world is not well known, perhaps, but the crucial role of its high-end glass in the lenses for aerial cameras is widely acknowledged. Now the company is returning to our consciousness with its proactive approach to automotive lidar.

While returning home, one of the authors noticed, on a large information screen in the beautiful Franz Josef Strauss Airport in München, a short video about the SOFIA observatory, the renowned 747-borne NASA project. Schott enjoyed a serendipitous mention: the telescope's primary mirror, 2.7 m in diameter, was cut from a blank of ZERODUR®, developed in Mainz and selected because it is a unique glass-ceramic material with zero thermal expansion.

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Stewart Walker is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

3 Information on Wild Heerbrugg, Wild Leitz and Leica supplied by Dr. Bernhard Braunecker, Leica Research Fellow (retired); e-mail correspondence 1 May and 12 August 2020.

4 Information on Vexcel Imaging supplied by Dr. Michael Gruber, Vexcel Imaging; e-mail correspondence 5 May 2020.