Polarized-light mineralogical transmission microscopy in 1890-1930

Many scholarly books on mineralogy and crystallography appeared in 1890-1930. Among these were works by Soret (1893), Groth (1905), Wallerant (1909), Rinne (1922a,b) and Friedel (1926). New editions appeared, even repeatedly, of popular textbooks or monographs by for instance H. Rosenbusch, G. Tschermak, C.F. Naumann, F. Rutley and E.S. Dana. These works reflect rapid developments in petrographic microscopes, techniques of observation and measurement, and consequent accumulation of knowledge. Weinschenk (1901 and later), Duparc and Pearce (1907), Wright (1911b), Johannsen (1914), Larsen (1921) and others wrote handbooks on the use of the microscopes. Weinschenk claims in an introduction to his book, that the enormous progress made in the science of petrography (Gesteinskunde) during the last one-third of the 19th century was solely due to the application of microscopic methods. Similarly, Bonney (1892) writes that the microscopic observations clarified many aspects of the genesis of rock formations worldwide, and of their subsequent alteration. These had previously been afflicted with various incorrect interpretations: “The microscope has dispelled many an illusion, and reduced a chaos to order.”

![Fig. 1. Polarizing microscopes from Swift & Son, London c. 1910 and E. Leitz, Wetzlar c. 1898. All such microscopes contain two Nicol prisms of Iceland spar.](image)

Morozewicz (1898) estimates that at least a third of the currently appearing literature in geology concerns microscopical petrography, which had then been progressing very rapidly. Hundreds if not thousands of new minerals were discovered, described and characterized crystallographically with the aid of polarizing microscopes in 1890-1930. Only a few examples will be given here: baddeleyite (Fletcher 1893), tarbuttite (Spencer 1908), natrochalcite (Palache
and Warren 1908), butlerite and ransomite (Lausen 1928). Sometimes, examination showed that minerals with two or more different names were identical; one instance of this was brazilite which turned out to be the same as Fletcher's baddeleyite. In the preface to his book on certain valuable applications of mineralogical knowledge, Berg (1915) states that “…today, hardly any major effort in ore prospecting takes place without the broad involvement of microscopical petrography, which is particularly important in determining the genesis of the deposit.”. However, even by 1930 many uncertainties in mineralogy remained. These were gradually resolved by new methods such as X-ray spectrometers, and later electron microprobes. These have in recent decades gradually taken over the tasks of the polarizing microscope, but our understanding of minerals and rocks is attributed more to its use than any other single instrument (to quote M.E. Gunter in J. Geosci. Educ. 52, p. 34, 2004).

Among steps of progress in petrographic techniques was the construction (Dick 1889, Fig. 1) of a microscope where the polarizer and analyzer are rotated in unison. This method (which was more practical than rotating the stage with the thin-section specimen) was soon improved upon by others such as Klein (1895), Sommerfeldt (1904, 1905) and Leiss (1910). Fedorow (1891) invented the so-called universal- or theodolite-stage which could be rotated about any axis; this was also improved later by C. Klein, F.E. Wright and others (see e.g. Leiss 1912 and E.A. Wülfing's design in Fig. 5). As an example of the use of this stage, the directions of the optical axes in many quartz grains in a thin section could be charted; their alignment might be due to tectonic deformation of the rock. Another clue to its value is provided by C.W. Correns in a 1957
centenary Festschrift for the instrument firm of R. Winkel: “… the study of characteristic minerals which were of importance for the oil industry was much advanced by the development of the universal stage.”.

Fig. 3. Thin section (~1 cm width) of a coarse-grained peridotite, seen without and with Nicol prisms. From Mackenzie and Adams: Rocks and Minerals, 1994.

Fuess (1891, 1896), Klein (1895), Leiss (1897b, 1898a,b, 1899b, 1908 and more), Hirschwald (1904) and Wright (1910, 1911a) presented many novel instruments from Fuess’ workshop. Czapski (1891a) and Lincio (1907) introduced new microscopes from Zeiss (Fig. 6) and Leitz (Fig. 1) respectively. In order to reduce costs, some attempts were made at using glass-plate reflectors as polarizers instead of Nicol prisms. Nodot's (1877) microscope of this type was manufactured at least until 1938. It was probably meant for use only in schools and by amateurs, as Leiss (1897c) and Cheshire (1923) consider glass-plate polarizers to be unacceptable in professional microscopes. Halle (1896, 1908) described improved methods in the construction of the various types of Nicol prisms, and Thompson (1905) published a comprehensive review of new or modified types; one more polarizing prism was invented in 1910 by E. Ritter and A. Frank of B. Halle Nachf. (see Wülfing 1918).

Various improvements were made on Bravais’ (1855) half-shade technique for measuring elliptically polarized light, for instance by Nakamura (1905) and Lummer and Kynast (1907). Berek (1913b) described a new type of compensator for petrographic microscopes, where a plate of Iceland spar (about 0.1 mm thick) or another suitable crystal may be rotated in order to change the difference in phase between two polarized rays continuously over wide limits. This type gained much popularity (cf. Ehringhaus 1940, Schumann and Piller 1950, Partington 1953, and a review in Handbuch der Physik, vol. 25/I, 1961) and it is still in use. Leitz (1915), Berek (1915-20), Ehringhaus (e.g. 1920) and others introduced further improvements in polarizing microscopes. Many scientists devised stage heaters (Fig. 6) in order to observe melting points and other changes in minerals and industrial raw materials, even at temperatures up to 1500°C (e.g. Sommerfeldt 1904, Doelter 1909, Wright 1913a, Endell 1921).
Development of specialized instruments for the measurement of refractive indices and axial angles of crystals continued, see e.g. Czapski (1891b), Friedel (1893), Klein (1895, employing immersion liquids), Viola (1897), Wallerant (1897), Wülfing (1898), Stöber (1898), Leiss (1899a,b, Fig. 2), Klein (1900, Fig. 2, 1902) and Wright (1908a). New demonstration equipment (such as projectors, Fig. 4) for mineralogical education was also constructed, by Pellin (1897), Leiss (1897-98, 1903), Brauns (1903b) and later by Kohl (1909), G. Halle (1910), Berek (1913a) and Tutton (1922), among others. It may be recalled that in Nicol prisms the unwanted ray was often disposed of by blackening their outside surfaces; this however could cause overheating in the case of arc lights in projectors. Special designs therefore appeared, where superfluous light was shunted out of the prism (Ignatowsky 1910, Steeg & Reuter 1914, p. 73-74). Some manufacturers offered simple types of microscopes for student use. Spectrometers allowing polarization analysis by means of Nicol prisms were produced (Fuess ca. 1910), as well as apparatus for microscopical examination of crystals in monochromatic light.

Phase changes and chemical equilibria at high temperatures between the main components of synthesized common rock-forming minerals were charted by the use of petrographic microscopes with heated stages. This research was pioneered at the Carnegie Institution of Washington (Fig. 6), for instance by Allen et al. (1909) on diopside, Fenner (1912) on the various forms of silica, Bowen (1914) on pyroxenes, Andersen (1915) on olivine, Rankin and Wright...
(1915) on calcium-aluminium silicates, Rankin and Merwin (1918) on magnesium-aluminium silicates, and Ferguson and Merwin (1919) on calcium-magnesium silicates. These authors point out the value of microscopically observable features that aid in unravelling the history of rock formations and the compositions of their constituent minerals: twinning, extinction angles of polarized light, zoning, evidence of resorption, and so on.


It should also be kept in mind here that scientists are interested in many crystalline materials in addition to the minerals found in nature. Thus, the making of cement for building purposes was known by the ancient Romans, but then largely forgotten until the mid-18th century. Late in the 19th century, a turning point in research on cement occurred when H. Le Chatelier (1882) and A.E. Törnebohm investigated its properties with polarizing microscopes. The journal Moniteur Scientifique (vol. 18(i), p. 294, 1904) refers to an 1895 source stating that in his 1887 doctoral thesis Le Chatelier distinguished the two chief constituents of cement clinker with the aid of this method. In 1906, an extensive study of crystallization processes and equilibria in composites of calcium-, aluminium-, and silicon oxides was initiated (Shepherd and Rankin 1909, and other papers), leading in particular to improved understanding of the properties
of Portland cement. An example of a stability-field diagram for two mineral constituents is shown in Fig. 6. Much of the knowledge which was acquired in such studies by means of polarizing microscopes (Rankin and Wright 1915), would not have been obtained by any other experimental methods available at that time (cf. Rankin 1916, Wright 1916). For a list of references on subsequent research in this field, see the paper by Tippmann (1931) who himself used Icelandic calcite as raw material in his cement mixtures.

Peck (1919), Endell (1921), Fisk (1934), Bayley (1937) and Hartshorne and Stuart (1950, p. 434-439) state that in the 1920s and 1930s important research similar to the above, was carried out on the composition and thermodynamics of metal oxides and carbonates in ceramics, industrial slags and the like. In the same way, knowledge was improved of the manufacturing processes of glass (e.g. Bowen 1918, Wright 1921), tiles, clays (Schurecht 1922), and refractory materials such as silicon and zircon oxides used for instance in the lining of furnaces and in high-tension insulators. Milligan (1927) has this to say on abrasive materials, which are used in a wide range of activities from dental repairs to the automotive industry: "The petrographic microscope and microscopic methods in general have proved invaluable tools for the study of abrasives and grinding wheels.". Such abrasive materials include aluminium oxide (i.e. emery and other modifications) originally recovered by mining but later man-made, and the much harder carborundum (SiC) which was produced in electrical furnaces from around 1890. After 1930 or so, X-ray methods were also employed in the analysis of these compounds.
The above comments on cements, abrasives, etc. may apply equally to zeolites, as microscope research on their structure has contributed to the creation of many new compounds in that class not found in nature. They have found a wide range of industrial applications.

Polarizing microscopes were directly or indirectly connected with progress in various other sectors of materials science in the early 20th century. For instance, they were quite indispensable in all research on liquid crystals which are the basis of modern flat television screens and computer displays; see a lengthy review of studies on these by Friedel (1922). Two other examples of materials with special properties may be mentioned here; in both cases, investigations on these properties began before 1940, and they became very important in electronics and communications technology in the second half of the century. One case concerns the development of new crystalline materials exhibiting large piezoelectric effects along with electric properties analogous to ferromagnetism. These so-called ferroelectric materials (such as BaTiO₃) are for instance used in electrical capacitors and in computer memories. The other case where polarizing microscopes were involved, concerns ferrite magnets which were discovered during investigations of crystals related to the mineral spinel (MgAl₂O₄) and to metal silicates of the garnet group. Crystalline anisotropy, as first noted in Iceland spar, is an essential characteristic of ferrites and other “hard” (i.e. high-coercivity) magnetic materials.

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This text is largely adapted from section 29.1 in the writer’s 2010 report "Iceland spar and its influence on the development of science and technology in the period 1780-1930", with updates to Nov. 2014. Most of the references quoted here may be found at the end of the report. The illustrations in this compilation are not identical to those in the report.

For developments in the use of polarizing microscopes to biology and micro-chemistry, see section 29.9 of the report. For progress in reflection microscopy with polarized light in 1900-20, see section 29.3. Some events in the latter field in 1920-30 are covered in section 39.1.

Leó Kristjánsson