

2. The reflected-light microscopy, description and function of a reflected-light microscope

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2. 1. The reflected-light microscopy

The light source

A high-intensity source is required for reflected- light studies, mainly because of the low brightness of crossed polar images. Tungsten-halogen quartz lamps similar to those in transparency projectors, are used and the tungsten light (A source) gives the field a yellowish tint. Many microscopists prefer to use a blue correction filter to change the light colour to that of daylight (C source). A monochromatic light source (coloured light corresponding to a very limited range of the visible spectrum) is rarely used in qualitative microscopy, but monochromatic filters for the four standard wavelengths (470 nm, 546 nm, 589 nm and 650 nm) could be useful in comparing the brightness of coexisting minerals, especially now that quantitative measurements of brightness are readily available.

The polarizer

Polarized light is usually obtained by using a polarizing filter, and this should be protected from the heat of the lamp by a glass heat filter. The polarizer should always be inserted in the optical train. It is best fixed in orientation to give east-west-vibrating incident light. However, it is useful to be able to rotate the polarizer on occasion in order to correct its orientation, or as an alternative to rotating the analyser.

The incident illuminator

The incident illuminator sits above the objective, and its purpose is to reflect light down through the objective onto the polished specimen. As the reflected light travels back up through the objective to the eyepiece it must be possible for this light to pass through the incident illuminator. Three types of reflector are used in incident illuminators (Fig. 1):

- a) The cover glass or coated thin glass plate (Fig. 1.a). This is a simple device, but it is relatively inefficient because of light loss both before and after reflection from the specimen. However, its main disadvantage when at 45° inclination is the lack of uniform extinction of an isotropic field. This is due to rotation of the vibration direction of polarized reflected light, which passes asymmetrically through the cover glass on returning towards the eyepiece. This disadvantage is overcome by decreasing the angle to about 23° , as on Swift microscopes.
- b) The mirror plus glass plate or Smith illuminator (Fig. 1.b). This is slightly less efficient than the cover glass but, because of the low angle (approaching perpendicular) of incidence of the returning reflected light on the thin glass plate, extinction is uniform and polarization colours are quite bright. This illuminator is used on Vickers microscopes.
- c) The prism or total reflector (Fig. 1.c). This is more efficient than the glass plate type of reflector but it is expensive. It would be 100 percent efficient, but half of the light flux is lost because only half of the aperture of the objective is used.

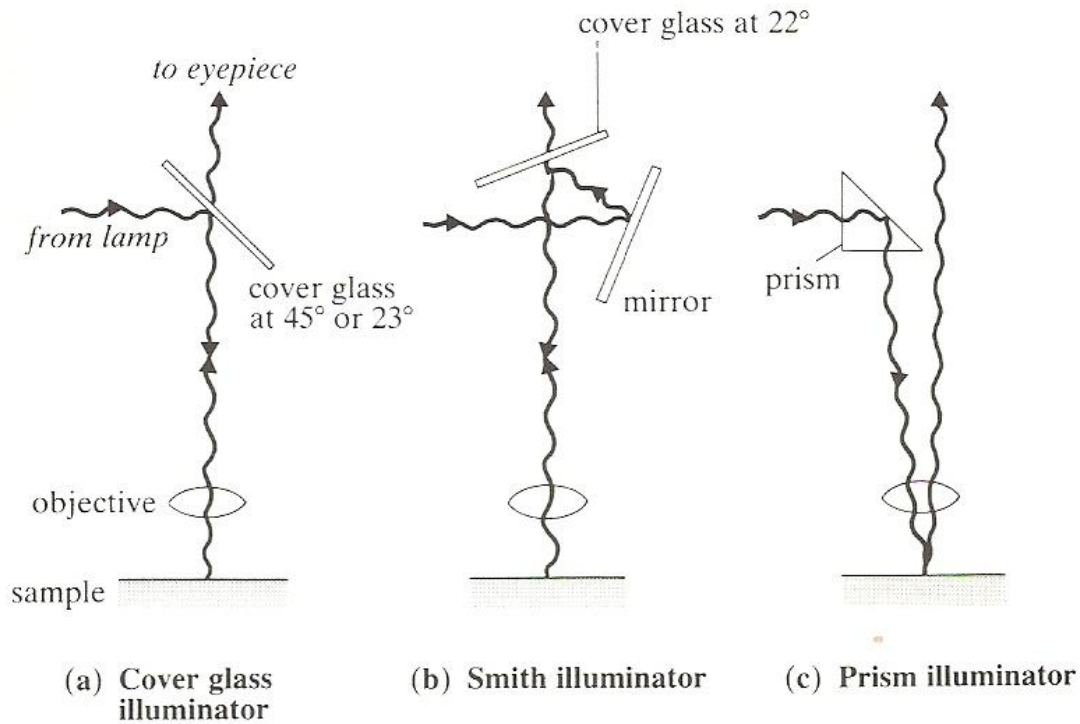


Fig. 1. Incident illuminators

Objectives

Objectives are magnifiers and are therefore described in terms of their magnification power, e.g. x 5. They are also described using numerical aperture (Fig. 2), the general rule being the higher the numerical aperture the larger the possible magnification. It is useful to remember that, for objectives described as being of the same magnification, a higher numerical aperture leads to finer resolved detail, a smaller depth of focus and brighter image. Objectives are designed for use with either air (dry) or immersion oil between the objective lens and the sample. The use of immersion oil between the objective lens and the sample leads to an increase in the numerical aperture value (Fig. 2). Immersion objectives are usually engraved as such.

Low-power objectives can usually be used for either transmitted or reflected light, but at high magnifications (>x10) good images can be obtained only with appropriate type of objective.

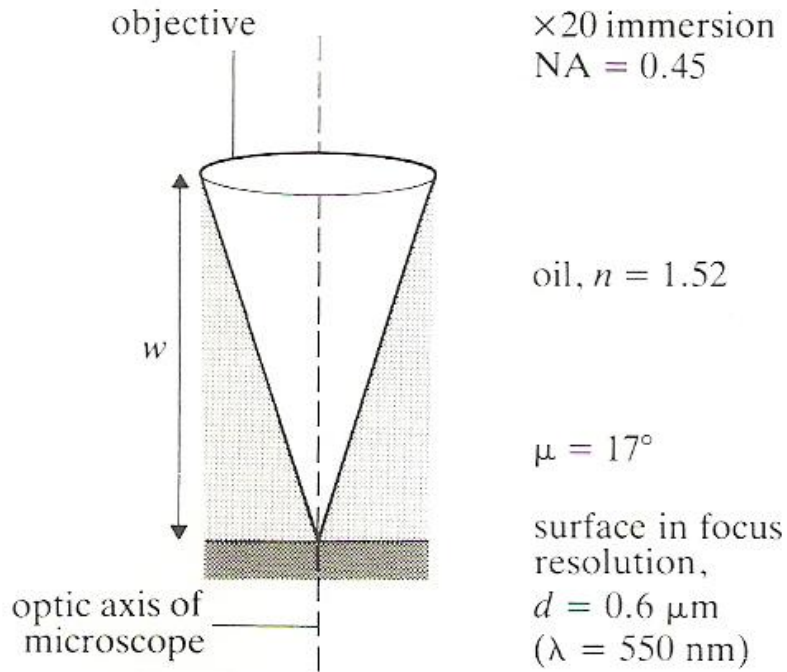


Fig. 2. The numerical aperture and resolution. $NA = n \sin \mu$, where NA is the numerical aperture, n is the refractive index of the immersion medium, and μ is half the angle of the light cone entering the objective lens (for air, $n=1.0$). $d = 0,5\lambda/NA$, where d = resolution (the distance between two points that can be resolved) and λ is in μm ($1 \mu\text{m} = 1000 \text{ nm}$). The working distance (w in the diagram) depends on the construction of the lens: for the same magnification, oil immersion lenses usually have a shorter distance than dry objectives.

Reflected-light objectives are also known as metallurgical objectives. Achromatic objectives are corrected for chromatic aberration, which causes colour fringes in the image due to dispersion effects. Planochromats are also corrected for spherical aberration, which causes a loss in focus away from the centre of a lens; apochromats are similarly corrected but suffer from chromatic difference of magnification, which must be removed by the use of compensating eyepieces.

Analyser

The analyser may be moved in and out of the optical train and rotated through small angles during observation of the specimen. The reason for rotation of the analyser is to enhance the

effects of anisotropy. It is taken out to give plane polarized light (PPL) the field appearing bright, and put in to give crossed polars (XPOLS), the field appearing dark. Like the polarizer, it is usually made of polarizing film. On some microscopes the analyser is fixed in orientation and the polarization is designed to rotate. The effect is the same in both cases but it is easier to explain the behavior of light if a rotating analyser is assumed.

The Bertrand lens

The Bertrand lens is little used in reflected-light microscopy, especially by beginners. The polarization figures obtained are similar to the interference figures of transmitted-light microscopy, but differ in origin and use.

Isotropic minerals give a black cross, which is unaffected by rotation of the stage but splits into two isogyres on rotation of the analyser. Colour fringes on the isogyres relate to dispersion of the rotation properties.

Light control

Reflected-light microscopes are usually designed to give Koler-type critical illumination (Galopin and Henry 1972). As far as the user is concerned, this means that the aperture diaphragm and the lamp filament can be seen using conoscopic light (Bertrand lens in) and the field diaphragm can be seen using orthoscopic light (Bertrand lens out).

A lamp rheostat is usually available on a reflected-light microscope to enable the light intensity to be varied. A very intense light source is necessary for satisfactory observation using crossed polars. However for PPL observations the rheostat is best left at the manufacturer's recommended value, which should result in a colour temperature of the A source. The problem with using a decreased lamp intensity to decrease image brightness is that this changes the overall colour of the image. Ideally, neutral density filters should be used to decrease brightness if the observed finds it uncomfortable. In this respect, binocular microscopes prove less wearisome on the eyes than monocular microscopes.

Opening of the aperture diaphragm decreases resolution, decreases the depth of focus and increases brightness. It should ideally be kept only partially open for PPL observation, but

opened fully when using crossed polars. If the aperture diaphragm can be adjusted, it is viewed using the Bertrand lens or by removing the ocular (eyepiece). The aperture diaphragm is shown correctly centred for glass plate and prism reflectors in Fig. 3.

The illuminator field diaphragm is used simply to control scattered light. It can usually be focused and it should be in focus at the same position as the specimen image. The field diaphragm should be opened until it just disappears from the field of view.

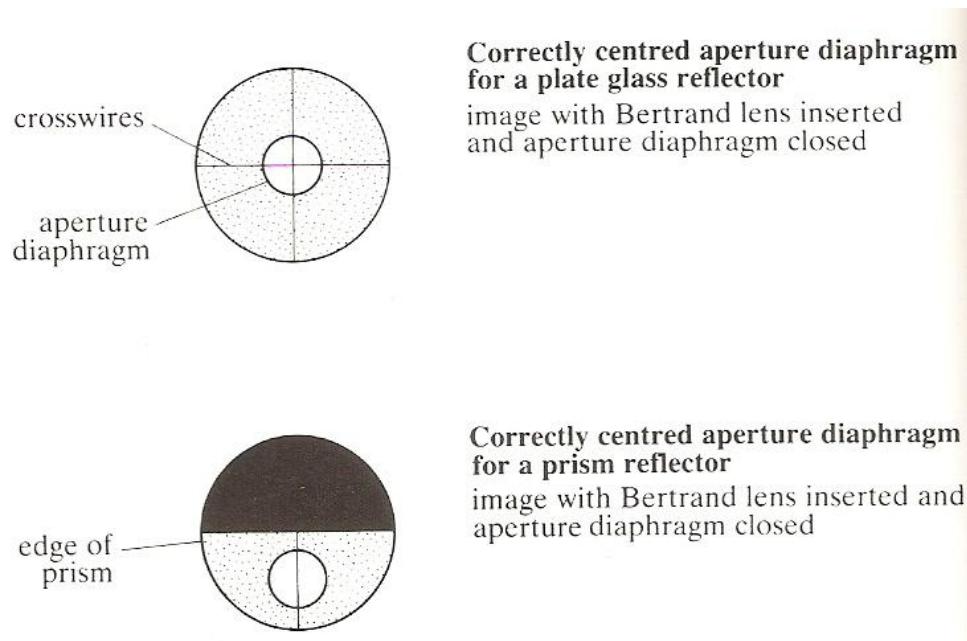


Fig. 3. Centring of the aperture diaphragm

2.2. The appearance of polished sections under the reflected-light microscope

On first seeing a polished section of a rock or ore sample, the observer often finds that interpretation of the image is rather difficult. One reason for this is that most students use transmitted light for several years before being introduced to reflected light, and they are conditioned into interpreting bright areas as being transparent and dark areas as being opaque, for polished sections the opposite is the case! It is best to begin examination of polished section such as that illustrated in Fig. 4 by using low-power magnification and

plane polarized light, under which conditions most of the following features can be observed:

- a) Transparent phases appear dark grey, because they reflect only a small proportion of the incident light, typically 3-15%. Bright patches are occasionally seen within areas of transparent minerals, and are due to reflection from surfaces under the polished surface.
- b) Absorbing phases (opaques or ore minerals) appear grey to bright white, as they reflect much more of the incident light, typically 15-95%. Some absorbing minerals appear coloured, but colour tints are usually very slight.
- c) Holes, pits, cracks and specks of dust appear black. Reflection from crystal faces in holes may give peculiar effects, such as very bright patches of light.
- d) Scratches of the polishes surfaces of minerals appear as long straight or curving lines, often terminating at grain boundaries or pits. Severe fine scratching can cause a change in the appearance of minerals. Scratches on native metals, for example, tend to scatter light and cause colour effects.
- e) Patches of moisture or oil tend to cause circular dark or iridescent patches, and indicate a need to clean the polished surface.
- f) Tarnishing of minerals is indicated by an increase in colour intensity, which tends to be rather variable. Sulphides, such as bornite, tend to tarnish rapidly. Removal of tarnishing usually requires a few minutes of buffing and repolishing.
- g) Polishing relief, due to the differing hardness of adjacent minerals, causes dark or light lines along grain contacts. Small soft bright grains may appear to glow, and holes may have indistinct dark margins because of polishing relief.

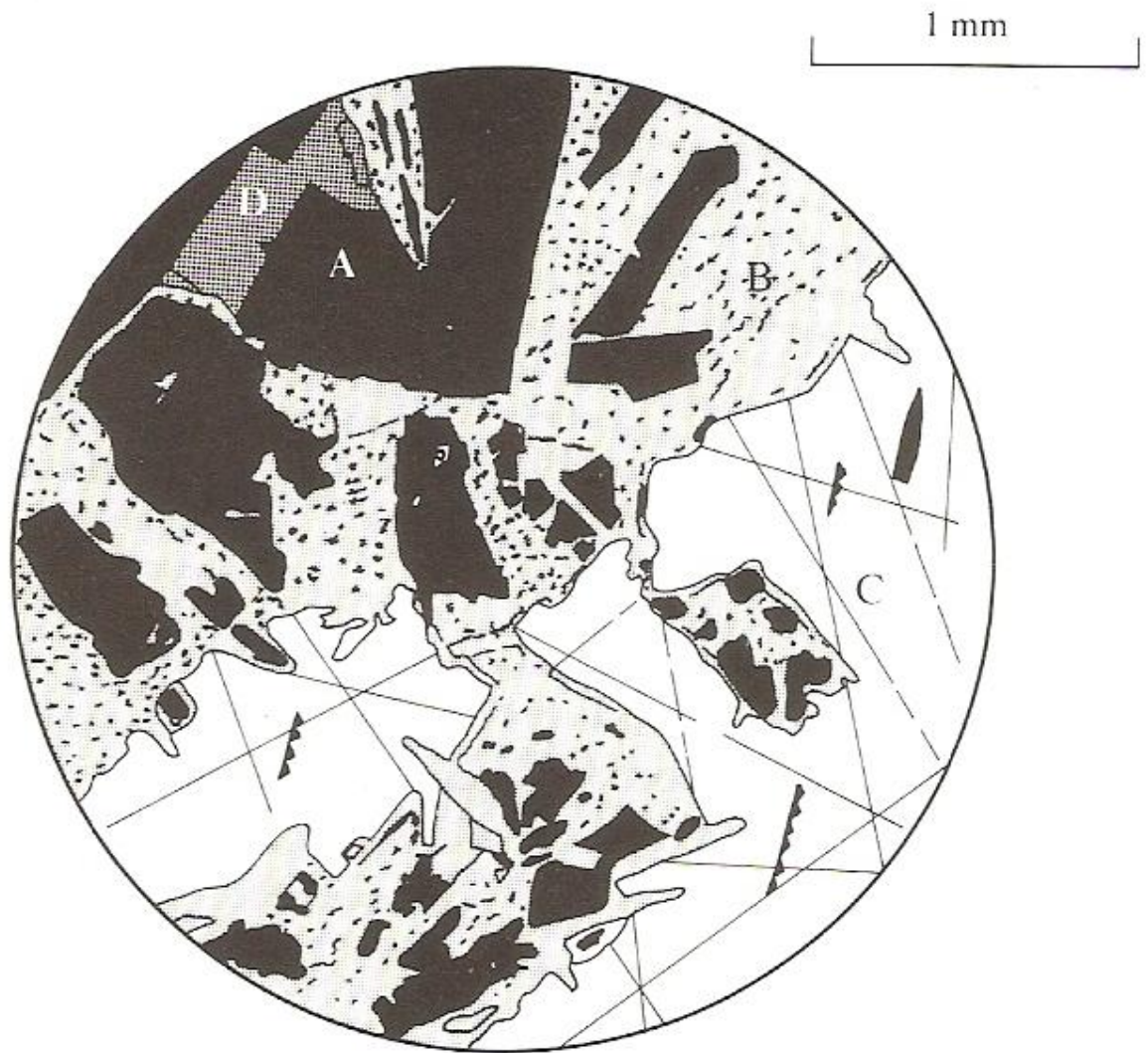


Fig. 4. A diagrammatic representation of a polished section of a sample of lead ore. Transparent phases, e. g. fluorite (A), barite (B) and the mounting resin (D) appear dark grey. Their brightness depends on their refractive index. The fluorite is almost black. Absorbing (opaque) phases, e.g. galena (C), appear white. Holes, pits and cracks appear black. Note the black triangular cleavage pits in the galena and the abundant pits in the barite which result not from poor polishing but from the abundant fluid inclusions. Scratches appear as long straight or curving lines; they are quite abundant in the galena, which is soft and scratches easily.

2.3. Preparation process of polished sections and polished thin-sections

The three common types of polish section are shown in Fig. 5 preparation of a polished surface of a rock or ore sample is a rather involved process which involves five stages:

- 1) Cutting the sample with a diamond saw.
- 2) Mounting the sample on glass or in a cold-setting resin.
- 3) Grinding the surface, flat, using carborundum grit and water on a glass or a metal surface
- 4) Polishing the surface, using diamond grit and oily lubricant on a relatively hard paper lap.
- 5) Buffing the surface, using gamma alumina powder and water as lubricant on a relatively soft cloth lap.

There are many variants of this procedure, and the details usually depend on the nature of the samples and the polishing materials, and the equipment that happen to be available. Whatever the method used, the objective is a flat, relief free, scratch-free polished surface. The technique used by the British Geological Survey is outlined by Lister (1978).

While covered thin sections continue to be popular for the study of rocks and polished blocks for ores, the polished thin section is undoubtedly the most versatile preparation, and is particularly suited to the study of samples containing a variety of minerals of low to high RI and of variable absorption. Variants include doubly polished thin section, which reveal the zoning of sphalerite, and ultra-thin (preferably doubly polished) sections, which reveal textural details in fine-grained carbonates. Partially polished (to coarse diamond grade) uncovered thin sections are popular for petrographic work using cathodoluminescence microscopy. Polished wafers are difficult and time-consuming to prepare, but are necessary for the study of fluid inclusions in transparent minerals (Shepherd et al. 1985). Examination of minerals using cathodoluminescence, ultraviolet fluorescence, lasers and electron-beam X-ray micro-analysis all require polished sections, and the use of these techniques therefore benefits from the preliminary reflected-light study of samples.

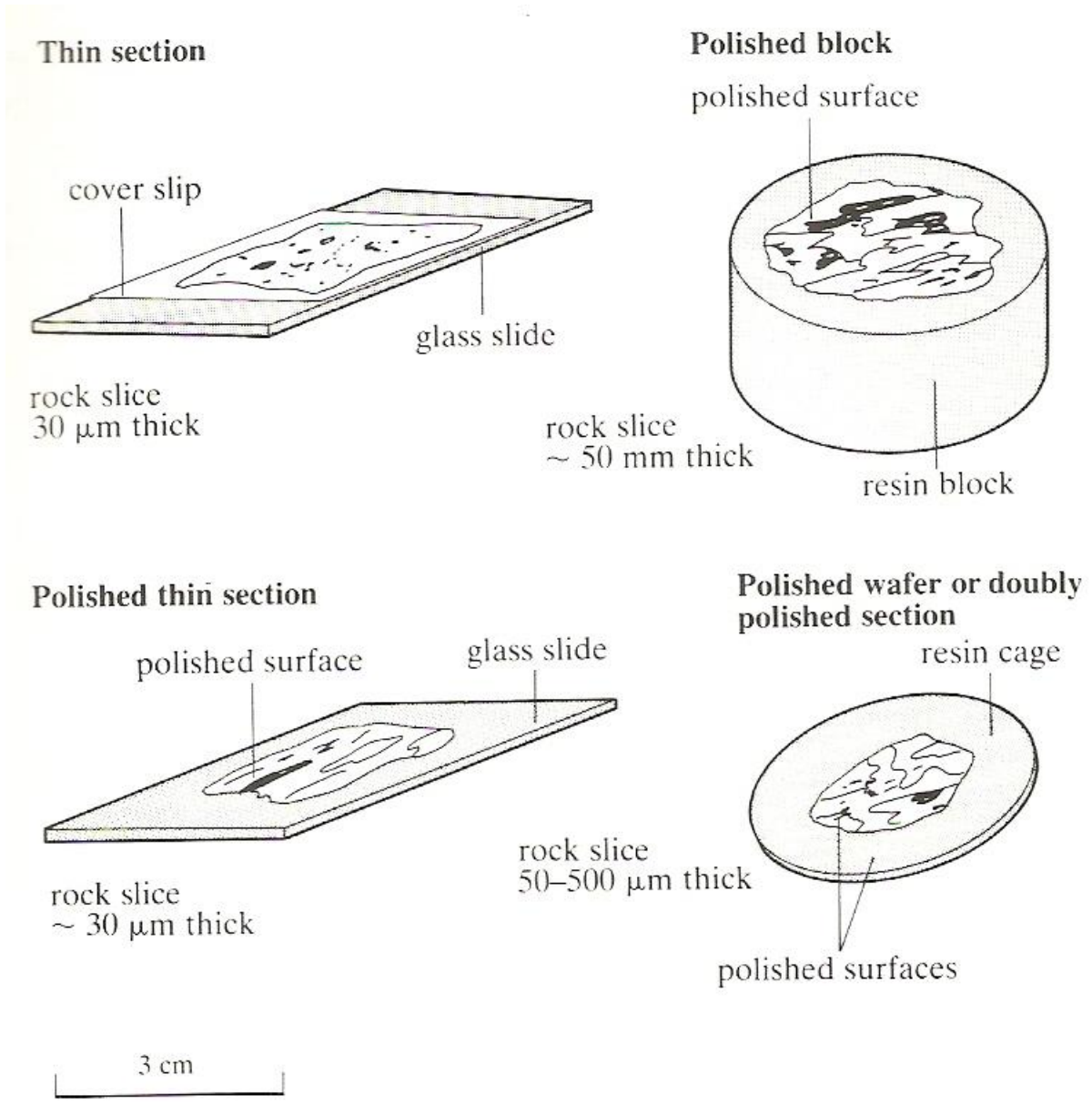


Fig. 5. Type of sections

2.4. Practical points on the use of the microscope (transmitted and reflected light)

Always focus using low power first. It is safer to start with the specimen surface close to the objective and lower the stage or raise the tube to achieve the position of focus. Polished samples must be level. Blocks may be mounted on a small sphere of plasticine on a glass plate and pressed gently with leveling device. Carefully machined polished blocks with parallel faces can usually be placed directly on the stage. A level sample should appear uniformly illuminated. A more exact test is to focus on the samples, and then close the aperture diaphragm (seen using the Bertrand lens) and rotate the stage. If the sample is level, the small spot of the light seen as the image should not wobble.

Good polished surfaces require careful preparation and are easily ruined. Never touch the polished surface or wipe it with anything other than a clean soft tissue, preferably moistened with alcohol or minerals. specimen not in use should be kept covered. The analyzer is usually fixed in orientation on transmitted light microscopes, but the polarizer may be free to rotate.

The approximate alignment of polarizer and analyzer for reflected light can be set fairly easily. Begin by obtaining a level section of a bright isotropic mineral such as pyrite. Rotate the analyzer and polarizer to their zero positions, which should be marked on the microscope. Check that the polars are crossed, i. e. the grain is dark. Rotate the analyzer slightly to give as dark a field as possible. View the polarization adjust the analyzer (and/or) polarizer until a perfectly centred black cross is obtained. Examine an optically homogeneous area of a uniaxial mineral such as ilmenite, niccolite or hematite. Using crossed polars it should have four extinction positions at 90° , and the polarization colours seen in each quadrant should be identical. Adjust the polarizer and analyzer until the best results are obtained (see Hallimond 1970) ensure that the stage is well centred using the high-power objective before studying optical figures.