

3.2 業務指導報告

3.2.1 はじめに

専門家の業務は、第1図に示すように、前期は供与機材据付のための場所・電気・水道設備などの確保に費やされ、体系的な技術指導は行われなかった。中期は供与機材の到着を待ちながら、供与機材を使用し研究ができるよう講義が実施された。後期は供与機材の据付・設置を行い、機材の調整、使用説明会、更に機材を用いた実験実習が行われた。

| | 1982 | | 1983 | | | | | | | | | | | |
|----------------------------|------|----------------------|----------------------|-----------|---|-----------|--|-------------------|---|--------------------|---|--------------------|---------------------|-----|
| | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| Steering Committee | | 1 ● | | ●2 | | | | ●3 | | | | 4 ● | 5 ● ● | 6 ● |
| Business | | Lecture by Sugaki | | | | | Lecture by Kano, Nambu, Mizota, Nakada & Hayashi | | | Setting equipments | | | Practice Chem analy | |
| Field or mine Survey | | La Paz, Potosi Uyuni | | San Jose | | | Huayna P | San Jose | | Potosi | | Sajama | Taqesi Indipend | |
| Equipment Arrival (La Paz) | | | ○ Kano Mizota Nakada | ○ Ford B. | | ○ Hayashi | ○ Type w. Copy m. | ○ Main equipments | | | | ○ Vacuum exhaust | | |
| Expert Stay | | Sugaki | | | | Kano | Mizota & Nakada | | | Hayashi | | Yemamoto & Higashi | JICA mission | |

第1図 鉱床学研究所プロジェクト日程表(昭和57年11月~58年10月)

講義は当初昭和58年1月上旬から実施される予定であったが、Cota Cota キャンパスの研究棟の完成が遅れたことと、それに伴う移転の遅れのため、3月下旬より実施せざるをえなかった。しかし、供与機材の到着が遅れたことが幸いし、6月下旬までに全専門家が予定の講義内容を消化できた。一方、供与機材の据付作業に約3ヶ月を予定していたが、全専門家の精力的作業とカウンターパートの全面的協力により、ほぼ1ヶ月足らずで終了できた。このため、当初の予定よりやや短かいながらも、残された期間を供与機材を使った実験実習活動にあてることができた。

講義では、昭和57年度が鉱床学研究所プロジェクトの初年度であるため、供与機材を用いた

研究を行なうための知識と、それに関連した鉱床学・鉱物学・岩石学各分野の基礎知識の教育を重視した。

昭和57年12月には、短期派遣専門家・苗木茂彦東北大学教授による「黒鉱鉱床」と「硫化鉱物の合成と相平衡」の特別講義が2回にわたって実施された。

実習は昭和57年度供与機材到着前にも、本プロジェクト開始以前の派遣専門家が購送機材として持参し供与された機器を用いて実施された。岩石顕微鏡実習、鉱石顕微鏡実習、X線回折実験実習、蛍光X線分析実習、熱分析実習、液体包有物実習などがそれである。

研究活動では、昭和57年11月下旬から12月中旬にかけて、La Paz, Potosi 地区の鉱山調査、Uyuni塩湖(Salar de Uyuni)調査が実施された。昭和58年3月上旬には、専門家・カウンターパート全員が参加してOruro市San Jose鉱山の調査が行われた。San Jose鉱山は6月中旬にも補足調査が行われている。7月上旬より8月中旬にかけては、文部省学術調査団(上野宏共東北大学助教授団長)と共に、Potosi 地区の鉱山調査が行われた。また、9月には、2ヶ所の火成岩類の野外調査が行われた。

室内実験としては、カウンターパートが従来行ってきた研究テーマについて、専門家との共同研究(San Jose鉱山の液体包有物研究・Taqesi 花崗岩類の岩石学的研究など)が実施されたほか、上記の野外調査で採集した岩石・鉱石試料について、各実験装置を用いて共同研究がなされた。

研究活動の内、San Jose鉱山については、昭和58年2月に専門家とカウンターパートが協議し、同鉱山のIto地区にある2鉱脈の多面的集中的共同研究を行うことを決定した。すなわち、鉱石鉱物の鉱物学的研究、鉱脈の微細構造研究、鉱山周辺の岩石学的研究、液体包有物研究、鉱山地域の変質作用研究などである。この共同研究は、専門家が供与機材の設置・調整や基礎実験実習に業務の大半の時間を費やさざるを得なかったため、全体を通してはまだ十分な成果を上げておらず、次年度への継続研究となっている。しかし、液体包有物研究、鉱床学的研究、鉱脈の微細構造研究などは着実に成果を上げている。特に、鉱山周辺の火成岩の化学分析研究が、湿式化学分析実習を重ねて溝田専門家の指導の下に、約1ヶ月間連日実施され、鉱床学研究所プロジェクト初年度にふさわしい成果を上げた。

これらの鉱山調査・火成岩調査および室内実験研究の成果は、本報告書第二部に掲載されている。

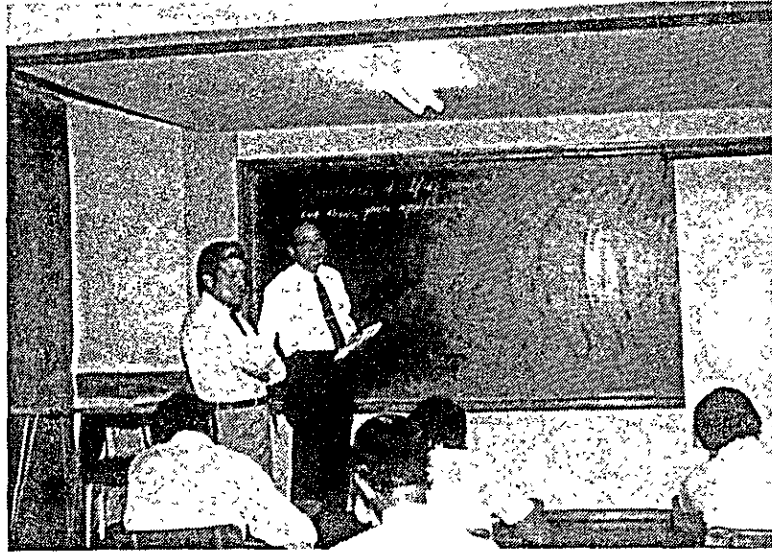


写真1 「Synthesis of sulfide minerals and their phase equilibrium」の特別講義をする菅木茂彦短期派遣専門家（昭和57年12月16日）。当時鉱床学研究所長のIng.O.Sanjinesがスペイン語への通訳をつとめた。

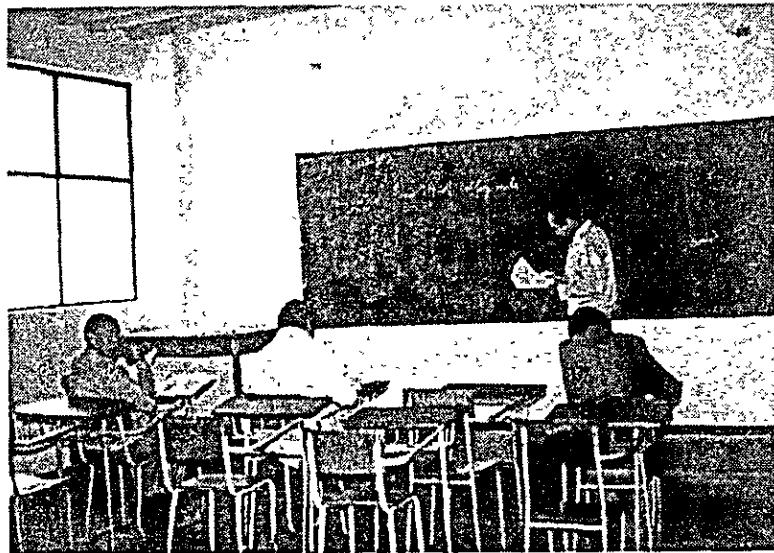


写真2 熱力学の講義をする鹿野新平チーフアドバイザー（昭和58年5月13日）。

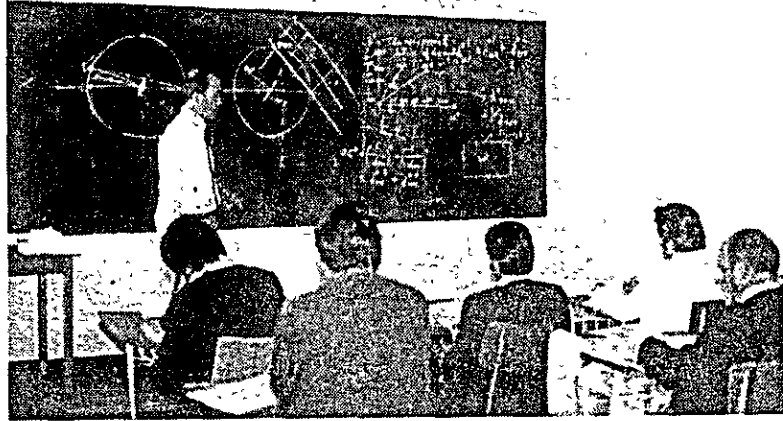


写真3 X線分析の講義をする溝田忠人専門家(昭和58年3月16日)。

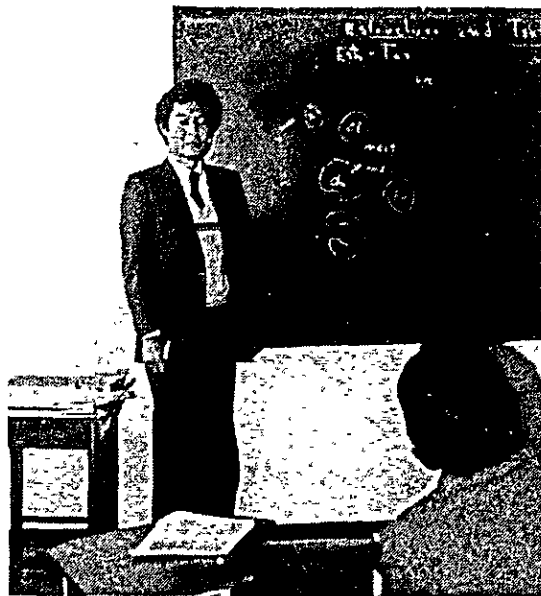


写真4 鉍石顕微鏡の講義をする林謙一専門家(昭和58年5月19日)。

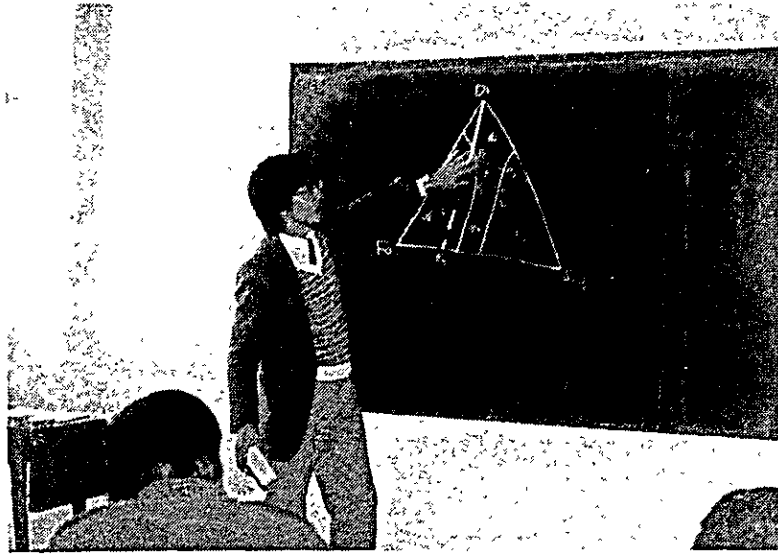


写真5 岩石学の講義をする中田節也専門家（昭和58年5月16日）。

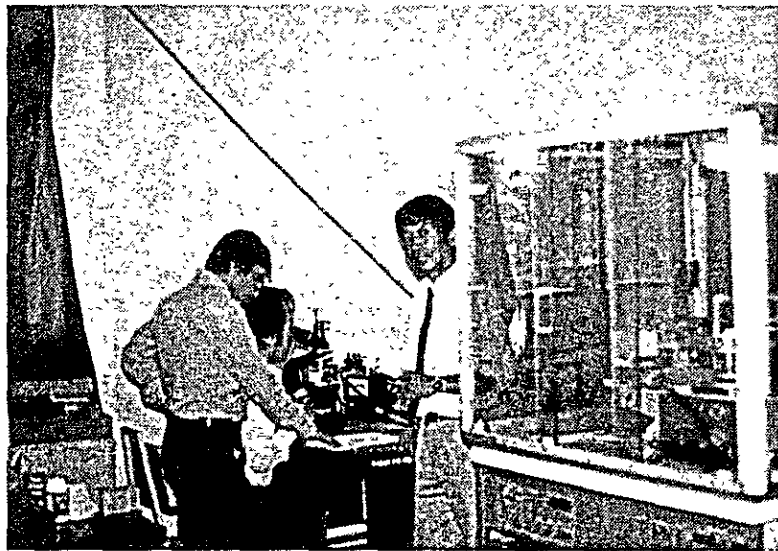


写真6 液体包有物の実習を担当する南部正光専門家と Ing.H.Villena, Sr.G.Sandi。



写真7 湿式化学分析の実習を担当する溝田忠人専門家と Sr. F. Saavedra。



写真8 同上。左より, Ing. E. Soria, Ing. H. Villena, 溝田忠人専門家, Ing. O. Sanjines

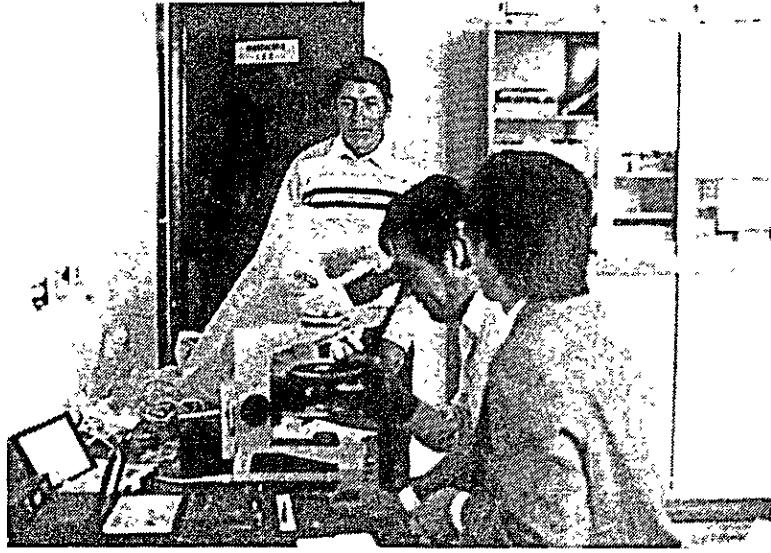


写真9 岩石顕微鏡の実習を担当する中田節也専門家と Sr. F. Saavedra, Sr. J. Castillo。

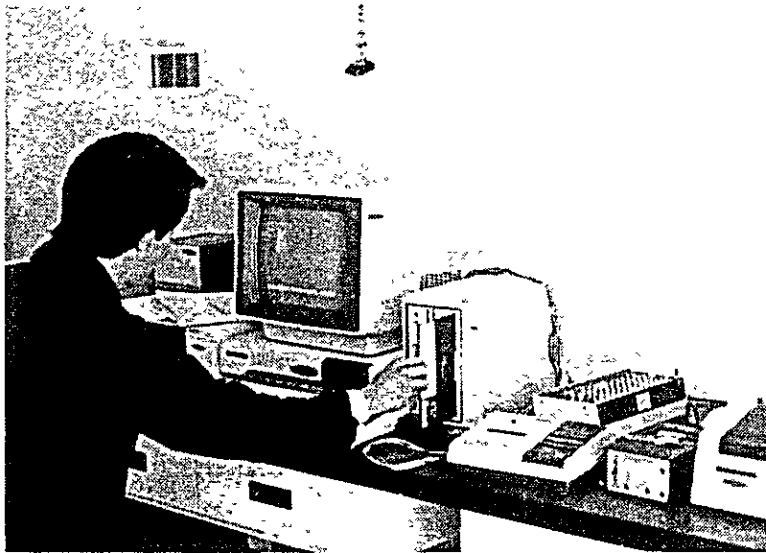


写真10 科学技術計算の実習を担当する林謙一郎専門家。



3.2.2 講 義

講義は昭和58年3月16日から6月27日まで1週間5科目各2時間ずつ行われた。講義科目時間割と担当専門家は第1表に示す通りである。このうち、火曜の「岩石鉱物の化学分析と分析機器」の時間の内3回は蛍光X線分析法の解説がなされた。木曜の「熱分析と液体包有物研究」の時間は、始め2回が南部専門家によって液体包有物研究の講義がなされ、4月以降は林専門家による「鉱石顕微鏡」の講義が、また6月に入って林専門家による液体包有物研究の講義が再び行われた。金曜の「鉱床学と鉱石顕微鏡」の時間は、鹿野チーフアドバイザーによって、主に鉱床学のための熱力学の講義が行われた。各講義科目の開催日、受講者名簿を第2表に掲げた。講義科目ごとの回数は最高12回、最低9回である。また受講者数は最高11名に達した。これは鉱床学研究所の教官以外に地球学科の教官や他の研究所（地殻変動学・湖沼学研究所、応用地質学研究所）の教官などが受講したためである。

各講義科目の担当専門家は、英文テキストを事前に準備し英語で講義を行った。以下に、各専門家が行った講義科目の解説と要旨あるいは重要と思われる講義内容を抜粋した英文テキストを載せる。これは、ボリヴィア国のカウンターパートが今後の研究において基礎知識のよりどころとなるよう配慮している。

第1表 講義科目と担当者

PROGRAM OF FUNDAMENTAL LECTURE

| | | |
|-----|--|----------------------------|
| MON | PETROLOGY AND PETROGRAPHIC MICROSCOPY | DR.S.NAKADA |
| TUE | CHEMICAL ANALYSIS FOR ROCKS AND MINERALS, AND ITS INSTRUMENTS | DR.T.MIZOTA |
| WED | X-RAY ANALYSIS FOR MINERALS | DR.T.MIZOTA |
| THU | THERMAL ANALYSIS, AND LIQUID INCLUSION STUDY | DRS.M.NAMBU & K.HAYASHI |
| FRI | ECONOMIC GEOLOGY AND ORE MICROSCOPY | DR.S.KANO |

第2表 講義開催日と出席簿

ATTENDANCE TABLE

Petrology and petrographic microscopy(by S.Nakada)

| DATE | 21 | 28 | 4 | 11 | 18 | 25 | 9 | 16 | 23 | 30 | 14 | 20 |
|------------|----|----|----|----|----|----|----|----|----|----|----|----|
| MONTH | MC | MC | AP | AP | AP | AP | MY | MY | MY | MY | JN | JN |
| A.Saavedra | o | o | - | o | o | o | o | o | o | - | - | o |
| O.Sanjines | - | - | - | - | o | o | o | o | o | - | o | o |
| M.Arduz | o | - | - | - | o | o | - | - | - | - | - | - |
| A.Sanchez | o | o | o | - | o | o | o | - | - | - | o | o |
| O.Velarde | - | - | - | - | o | - | - | o | o | o | o | - |
| H.Villena | o | o | o | o | - | o | - | - | o | o | o | o |
| G.Beccar | - | o | - | o | - | o | o | o | - | - | - | - |
| F.Saavedra | o | o | o | o | - | o | o | o | o | o | o | o |
| E.Soria | - | - | o | o | o | o | o | o | - | o | o | - |
| G.Sandi | o | - | - | - | - | - | - | - | - | - | - | - |

Chemical analysis for rocks and minerals, and its instrument
(by T.Mizota)

| DATE | 22 | 29 | 5 | 12 | 19 | 26 | 10 | 17 | 24 | 7 | 14 |
|------------|----|----|----|----|----|----|----|----|----|----|----|
| MONTH | MC | MC | AP | AP | AP | AP | MY | MY | MY | JN | JN |
| O.Sanjines | o | o | o | o | o | o | o | o | - | o | o |
| M.Arduz | o | - | o | o | o | - | - | - | - | - | - |
| A.Sanchez | o | - | o | o | o | o | o | - | o | o | o |
| O.Velarde | o | - | o | o | - | o | o | - | o | o | o |
| H.Villena | - | o | o | o | - | - | o | - | o | o | o |
| G.Sandi | o | o | - | - | o | o | o | o | o | o | o |

* X-ray fluorescence analysis lecture(24 May to 14 Jun)

X-RAY ANALYSIS FOR MINERALS(by T.Mizota)

| DATE | 16 | 23 | 6 | 13 | 20 | 27 | 4 | 18 | 25 | 1 | 8 | 15 |
|--------------|----|----|----|----|----|----|----|----|----|----|----|----|
| MONTH | MC | MC | AP | AP | AP | AP | MY | MY | MY | JN | JN | JN |
| O.Sanjines | o | o | o | o | o | | | o | o | o | o | o |
| A.Sanchez | o | o | o | o | o | | | - | o | - | o | o |
| O.Velarde | o | o | - | o | o | | | - | - | - | o | o |
| H.Villena | o | o | o | - | o | | | - | o | - | o | o |
| F.Saavedra | o | o | - | - | - | | | - | - | - | o | o |
| G.Sandi | - | o | o | o | o | | | - | o | o | o | o |
| R.Gondoretti | o | o | - | - | - | | | - | - | - | - | - |
| T.Hunoz R. | - | o | o | - | - | | | - | o | - | - | - |

MC:March, AP:April, MY:May, JN:June

(continued)

Thermal analysis, and liquid inclusion study (by M.Nambu and K.Hayashi)

| DATE | 17 | 18 | 9 | 22 | 23 |
|-------------|----|----|----|----|----|
| MONTH | MC | MC | JN | JN | JN |
| O.Sanjines | o | o | o | | |
| A.Sanchez | - | - | o | | |
| H.Villena | - | - | o | | |
| G.Sandi | o | o | o | | |
| T.Hunoz R. | o | o | - | | |
| L.A.Rodrigo | o | o | - | | |
| F.Saavedra | - | - | o | | |

* 17 and 18 March by M.Nambu

Ore microscopy (by K.Hayashi)

| DATE | 28 | 12 | 19 | 26 |
|------------|----|----|----|----|
| MONTH | AP | MY | MY | MY |
| A.Saavedra | o | o | o | o |
| O.Sanjines | o | - | - | o |
| A.Sanchez | o | - | - | o |
| F.Saavedra | o | o | o | o |
| G.Sandi | o | o | o | o |

Economic Geology (by S.Kano)

| DATE | 25 | 8 | 15 | 22 | 6 | 13 | 20 | 27 | 3 | 10 |
|-------------|----|----|----|----|----|----|----|----|----|----|
| MONTH | MC | AP | AP | AP | MY | MY | MY | MY | JN | JN |
| A.Saavedra | o | o | o | o | o | - | o | - | | - |
| O.Sanjines | o | o | o | o | o | o | o | o | | o |
| A.Sanchez | o | o | o | o | o | - | - | o | | o |
| O.Velarde | o | - | o | o | - | - | - | - | | o |
| H.Villena | o | - | o | - | - | - | - | - | | - |
| G.Beccar | o | o | - | o | o | - | - | - | | - |
| F.Saavedra | o | o | o | o | o | o | o | o | | o |
| G.Sandi | o | o | o | o | o | - | - | o | | o |
| L.A.Rodrigo | o | - | - | - | - | - | - | - | | o |
| F.Blanco | o | - | - | - | - | - | - | - | | - |
| J.Munoz R. | o | - | - | - | o | o | o | o | | o |

Petrology and petrographic microscope

Setsuya Nakada

Outline of lecture entitled "Petrology and petrographic microscope"

These 12 two-hour lectures were held by Dr. S. Nakada from March 21 to May 20, 1983. Optical principles and the operation of petrographic microscope were mainly covered. The classifications of igneous rocks, phase petrology, geochemistry of igneous rocks were also lectured. The content is as follows.

- 1st: Japanese Quaternary volcanic rocks (including self-introduction)
- 2nd to 4th: Optical principles of petrographic microscope
- 5th: Calculating method of C.I.P.W. norm
- 6th: Classification of volcanic rocks and phase petrology(1)
- 7th to 8th: Phase petrology(2 to 3)
- 9th: Phase petrology(4) and stereographic projection(1)
- 10th: Stereographic projection(2) and classification of granitic rocks(1)
- 11th: Classification granitic rocks(2) and geochemistry of igneous rocks(1)
- 12th: Geochemistry of igneous rocks(2)

The text appearing below is a digest of optical principles of petrographic microscope, the immersion method, a method how to use the universal stage, an easy experimental method to determine the composition of plagioclase, and the calculating method of C.I.P.W. norm. Two Japanese books(Tsuboi, S.(1959), Polarized microscope, Iwanami Shoten, 305p; Miyashiro, A. and Kushiro, I.(1975), Petrology II, Kyoritsu Zensho, 171p) were referred to summarize it.

Preface

We know that the petrographic microscope (polarized microscope) is very useful instrument for the study of fine solid materials in the field of petrology. The petrographic microscope is so basic that we can not start to study petrology without the instrument and the knowledge on optical principle. We can also identify some minerals by other methods; such as chemical analysis, X-ray analysis etc. By optical observation, however, we can easily and rapidly determine very fine minerals, small parts, inclusions and rock texture. The information on rock texture or structure observed under the microscope is very important. Through that we can understand the condition in which the rock or the mineral was formed. By mineral composition or by the chemical composition of rock, we can not speculate where a given igneous rock was formed. Therefore, even if many useful and convenient instruments are invented, we must continue to use the petrographic microscope as the most basic and important instrument for petrology and mineralogy.

Optical principles

1) Introduction

Optically transparent materials are divided into two varieties: isotropic (cubic and amorphous) and anisotropic materials. Furthermore the anisotropic materials are classified into uniaxial and biaxial substances. Within the anisotropic substances, a light from one source separates into two independent polarized lights, with velocities of which are different, and for which the directions of their oscillation are normal to each other.

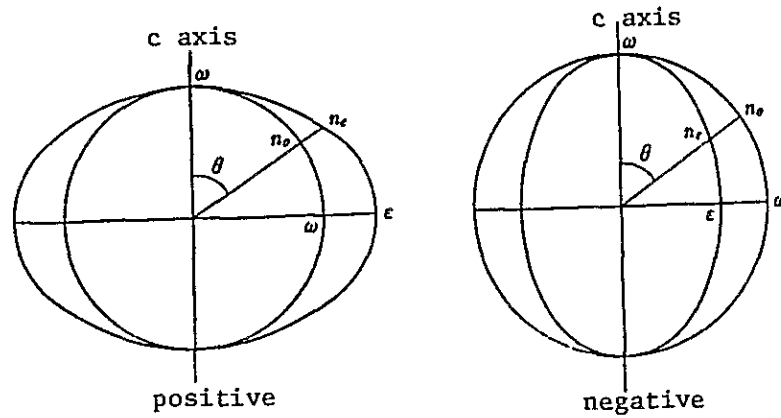


Fig.-1 Index surface of uniaxial crystal

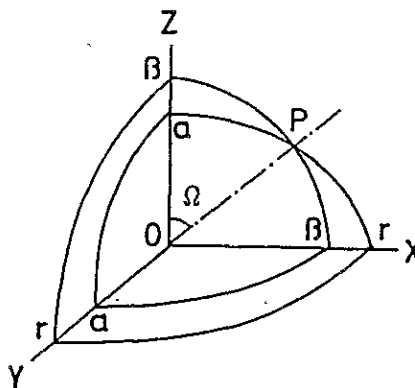


Fig.-2 Index surface of biaxial crystal

2) Index surface

The INDEX SURFACE is very important for us to observe minerals under the microscope. The INDEX SURFACE represents refractive indices in any directions from one point in a given substance. In the case of uniaxial crystal, we can draft the INDEX SURFACE as shown in Figure-1. In the anisotropic materials, there are two distinct refractive indices in each direction. This phenomenon is called DOUBLE REFRACTION or BIREFRINGENCE. The degree of the BIREFRINGENCE is represented as " $n_1 - n_2$ ": difference of two indices in a given direction. On the other hand, the direction in which there is no double refraction is called OPTIC AXIS. "Optically uniaxial" means that the material has one optical axis, while "optically biaxial" means two optical axes in the material. Optic axis in a uniaxial crystal is always parallel to the c-axis of the crystal. The index surface of biaxial crystals can be drawn as shown in Figure-2. This is more complex than that of uniaxial crystals. Figure-2 shows the eighth of the index surface. Here, X, Y and Z are the optical elasticity axes. α , β and γ are principal refractive indices ($\alpha < \beta < \gamma$). 2Ω is optical angle ($2V$ or $180^\circ - 2V$) or optic axial angle. If 2Ω is greater than 90° , $180 - 2\Omega$ is the angle $2V_x$ (negative). When 2Ω is smaller than 90° , the character is positive ($2V_z$). Axes X and Z in Figure-2 mean bisectrix of optic axial angle. The plane including two optic axes is called OPTIC AXIAL PLANE. The angle Ω is represented by α , β and γ as follows,

$$\sin \Omega = \frac{\gamma}{\beta} \sqrt{\frac{(\beta + \alpha)(\beta - \alpha)}{(\gamma + \alpha)(\gamma - \alpha)}}, \quad \cos \Omega = \frac{\alpha}{\beta} \sqrt{\frac{(\gamma + \beta)(\gamma - \beta)}{(\gamma + \alpha)(\gamma - \alpha)}}$$

$$\text{and } \tan \Omega = \frac{\gamma}{\alpha} \sqrt{\frac{(\beta + \alpha)(\beta - \alpha)}{(\gamma + \beta)(\gamma - \beta)}}$$

3) Vibration direction of polarized light in uniaxial crystal

Extraordinary light vibrates within a plane including its advancing direction and optic axis, and perpendicular to the advancing direction (Figure-3). Ordinary light vibrates perpendicular to both of the above plane and the advancing direction. Usually the vibration direction of the faster light is referred to as "X'", while that of the slower one as "Z'". We can easily determine such vibration direction under the microscope. To determine the direction of X' or Z' is much important for the determination of refractive index or optic sign of crystal.

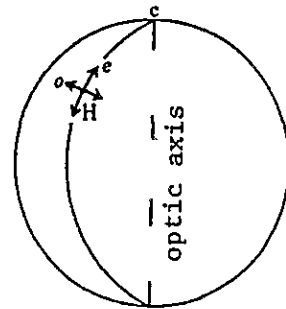


Fig.-3 Biot-Fresnel's rule for uniaxial crystal

4) Vibration direction of polarized light in biaxial crystal

According to the Biot-Fresnel's rule, we can find vibration direction of a polarized light which passes through one point on index surface (Figure-4).

1. Consider one direction H of an advancing light.
2. Consider two great circles connecting the direction H with optic axes A and B stereographically.

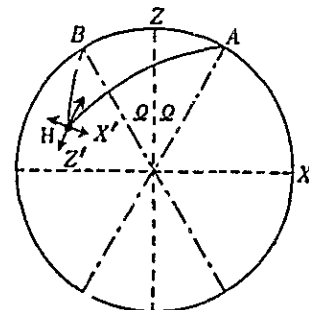


Fig-4 Biot-Fresnel's rule for biaxial crystal

3. Here, we get a spherical triangle ABH. Slow polarized light Z' vibrates in the direction of bisectrix of angle ABH facing optic elasticity axis Z. Faster polarized light X' vibrates in the direction of bisectrix of the external angle of H, and also perpendicular to Z'.

Here, we can obtain the definitions of the optic elasticity axes; that is, the vibration direction of the fastest light is the direction of the optic elasticity axis X, and the vibration direction of the slowest light is the direction of Z. The direction perpendicular to the both is that of Y. In Figure-5, vibration direction of lights passing through the planes XY, YZ and ZX is shown.

Uniaxial positive crystal is regarded as biaxial positive crystal with $2V_z=0^\circ$, while uniaxial negative crystal is as biaxial negative crystal with $2V_x=0^\circ$. Vibration direction of polarized lights in uniaxial crystal can be also determined with the Biot-Fresnel's rule (Figure-3). In this case, an interior angle of spherical triangle (AHB in Figure-4) would be zero.

5) Optical orientation

Optical orientation in a crystal means the relation of optic elasticity axis, optic axis and crystal axis. Tetragonal and hexagonal crystals belong to uniaxial group. In orthorhombic crystal, each optic elasticity axis is parallel to each crystal axis. In monoclinic crystal, one optic elasticity axis is parallel to one of the crystal axes. In triclinic crystals, the optic elasticity axes are independent of the crystal axes.

6) Observation of optically anisotropic crystal under the microscope

When we observe optically anisotropic crystals under crossed nicols, we observe four times of darkness during one rotation of the microscopic stage. This phenomenon of darkness is called EXTINCTION. The angle between two extinction positions is 90° . The position where the stage is rotated at 45° from the extinction position is called DIAGONAL POSITION.

Let's consider a light coming toward us perpendicular to this paper. PP' and QQ' are vibration directions of polarizer and

analyzer, respectively, in Figure-6.

AA' and BB' represent vibration directions of faster and slower lights, respectively, in thin section. The angle between AA' and PP' is θ . When a polarized light with the amplitude of A enters into a polar, generally, the amplitude of the passed light is represented by $A\cos\theta$: that is, when θ is zero, whole light can pass through, while the light is intercepted by the polar when $\theta=90^\circ$. An amplitude of the vibration of the transmitted light is determined by simple "vector principle" which is employed in the resolution of forces. A polarized light vibrating in the direction of PP' separates into new two polarized lights in an anisotropic material. The two vibrate in the direction of AA' and BB'. If the amplitude of source-light is OP, the amplitude of polarized lights AA' and BB' are OA and OB respectively. After passing through the anisotropic material, the components of the two lights in the direction QQ' can only pass through the analyzer. The amplitudes are OQ and OQ'.

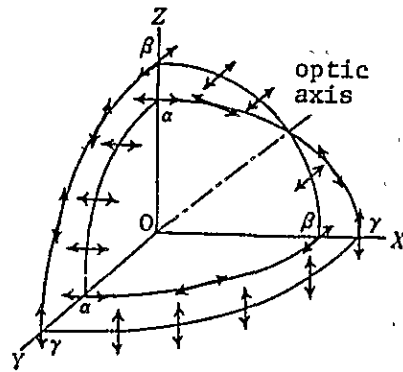


Fig.-5 Vibration direction of lights and index surface of biaxial crystal

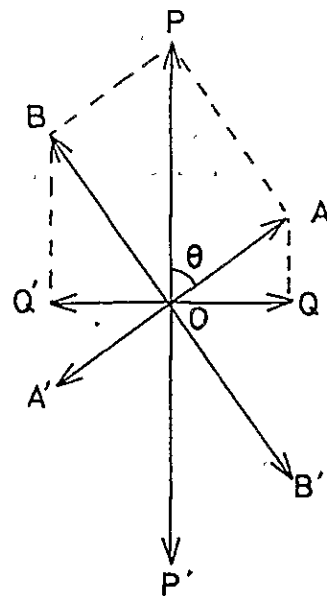


Fig.-6 Relationship of vibration directions between nicols and mineral

Amplitude of the synthesized wave which we can observe is written as,

$$A'^2 = A^2 \sin^2 2\theta \sin^2 [\pi d(n_2 - n_1) / \lambda_0]$$

Where A is an amplitude of source-light, d is thickness of thin section, and λ_0 is wave length of light in air. A'^2 represents the brightness of the synthesized wave. The way to introduce this equation is not so difficult, but this explanation is omitted here. This equation is very important.

When θ is $0^\circ, \pi/2, \pi, \dots$, $\sin^2 2\theta = 0$ and $A'^2 = 0$

This is in the extinction condition.

When θ is $\pi/4, 3\pi/4, 5\pi/4, \dots$, $\sin^2 2\theta = 1$ and $A'^2 = \text{maximum}$.

This is the diagonal position.

Furthermore, when θ is constant, the brightness is determined by " $d(n_2 - n_1)$ " and wave length of the source-light.

When $d(n_2 - n_1) = p\lambda_0$, $A'^2 = 0$

When $d(n_2 - n_1) = (2p+1)\lambda_0/2$, $A'^2 = \text{maximum}$.

(where $p=1, 2, 3, \dots$)

We will now consider about how long the slow polarized light is delayed against the fast polarized light during the passage in anisotropic materials. Thickness of thin section is d, and wave lengths of polarized lights are λ_1 and λ_2 for the fast and slow lights respectively. The fast light passes through the thin section by the oscillation of d/λ_1 times, and the slow light does by d/λ_2 (Figure-7). The latter is delayed by the oscillation of $d(1/\lambda_2 - 1/\lambda_1)$ times against the former. When the slow light goes out of the thin section, the fast light advances by the distance of $\lambda_0(d/\lambda_2 - d/\lambda_1)$. This term means the retardation distance of the slow light against the fast light in the section. This is called RETARDATION of thin section or crystal. Since $\lambda_0/\lambda_2 = n_2$ and $\lambda_0/\lambda_1 = n_1$, we can write this term as $R = d(n_2 - n_1)$. This was already understood in the representation of the brightness of light passing through thin section under crossed nicols. Retardation is represented in $m\mu$. For example, consider a thin section with

$R/\lambda_0 = 1$ by blue-colored light ($\lambda_0 = 460 \text{ m}\mu$). In this case, the brightness of the blue-colored light in this section is zero; that is, the blue-colored light disappears in the section. However, other lights with wave length different from $460 \text{ m}\mu$ (for example, yellow- and red-colored lights) do not disappear. When the thin section is observed by white light, the INTERFERENCE COLOR is observed to be mixed color of yellow and red.

Generally we can refer to retardation of thin section or maximum birefringence in a crystal with the interference color chart of "michel-Levy". When colored minerals are observed under crossed nicols, the color of the mineral must be taken into consideration. When a color different from the interference color chart is observed after the above treatment, the color is called ANOMALOUS INTERFERENCE COLOR or ABNORMAL INTERFERENCE COLOR. The reason why anomalous interference color appears, is changeable retardation of the mineral depending on wave lengths of a source-light.

7) How to determine the directions of X' and Z'

To determine the vibration direction of two polarized lights in thin section of a given mineral, we move the section to the extinction position under crossed nicols. Because the extinction results from the coincidence of vibration direction of polarized light through the mineral with that of analyzer or polarizer.

To determine whether the vibration direction is X' or Z', we may apply the principle of putting a thin section upon another; that is, the usage of test plate.

After a mineral is moved into the diagonal position (one of the vibration directions is NE), the test plate is inserted. "If X' and Z' of the mineral are parallel to those of the test plate, we observed the interference color by adding two retardations (mineral and test plate). If X' and Z' of the mineral coincide with Z' and X' of the test plate, respectively, the interference color is given by the subtraction of the two retardations." Thus,

we can easily determine X' and Z' ;
in a given mineral in thin section.

8) Optical sign of elongation

The angle between the conspicuous outline of the mineral and one of the vibration direction is called the extinction angle η (Figure-8). When $\eta=90^\circ$ or 0° , the section shows STRAIGHT EXTINCTION. When η is not equal to 0° or 90° , the section shows OBLIQUE EXTINCTION.

When a mineral is elongated in one direction and shows the straight extinction in a thin section, we usually use terms of NEGATIVE ELONGATION or POSITIVE ELONGATION. This term is different from the optical character of crystal. When the direction of the elongation is parallel to Z' , we say that the mineral shows positive elongation. The contrary means negative elongation.

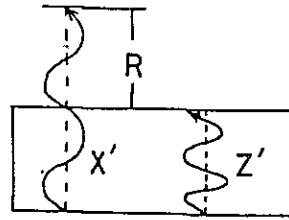


Fig. 7 Schematic illustration of retardation

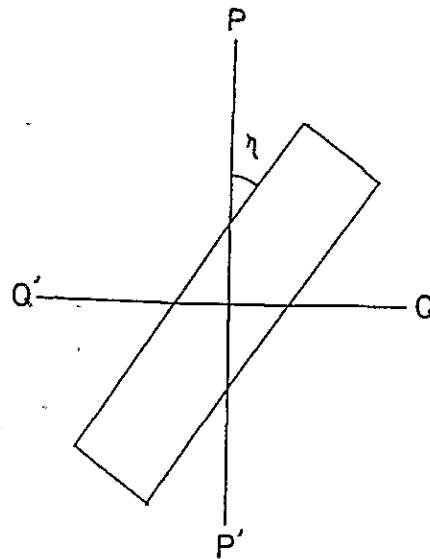


Fig. 8 Oblique extinction
The contrary means negative elongation.

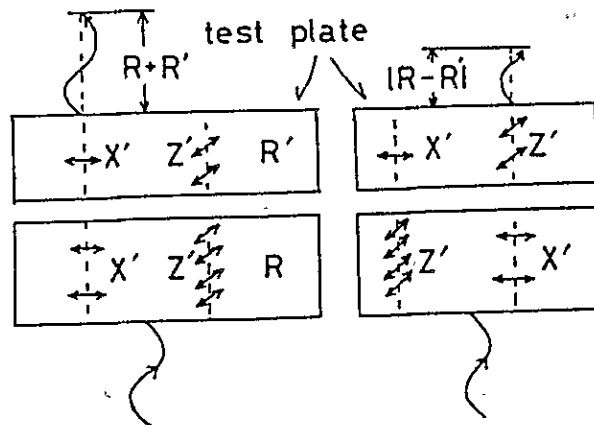
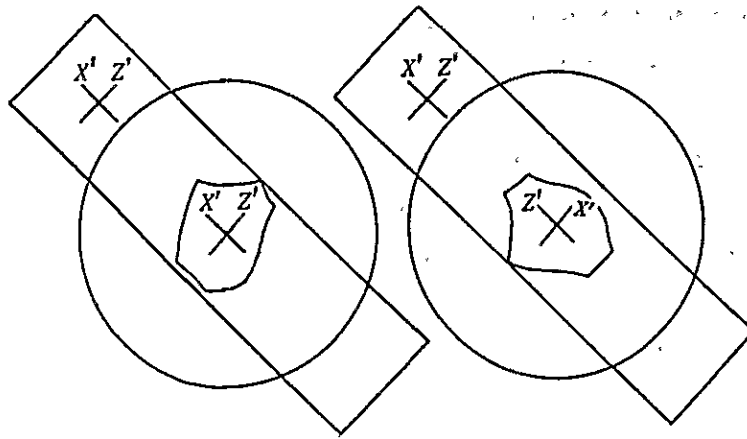


Fig.-9 Addition and subtraction relation of retardations between test plate and mineral. This is important to determine the vibration directions of X' and Z' . Left: addition, and right: subtraction.

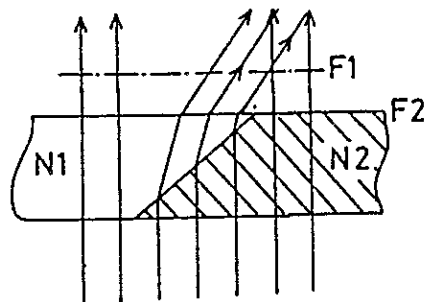


Fig.-10 Ray refraction along a boundary of two substances with different refractive indices ($N2$ is greater than $N1$). Upward moving of focus from $F2$ to $F1$ causes moving of bright zone (represented by arrows with narrow intervals) to the right-hand side.

9) Rule of Becke's line(Becke line)

We can observe a little bright line or zone along the boundary between the minerals in thin section under the microscope, especially when light is stopped down. This line is called BECKE'S LINE or BECKE LINE. By the usage of this line, we can assign which mineral or substance has higher refractive index. "The increase of the distance between the thin section and the objective lens results the movement of the Becke's line into the material with higher refractive index(Figure-10). On the other hand, the decrease of the distance causes the movement into the mineral with lower refractive index." This rule is applied also to measuring refractive index by the immersion method.

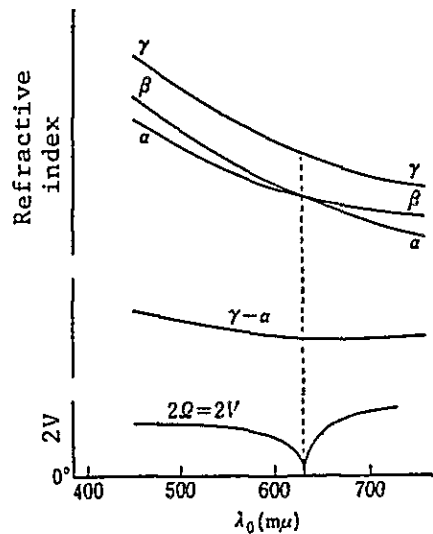


Fig.-11a Dispersion of refractive indices, birefringence and $2V$ in a biaxial crystal

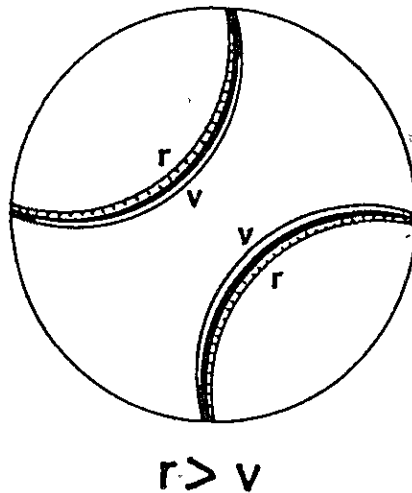


Fig.-11b Consociation figure of a biaxial crystal. Red-colored isogyres show greater $2V$ than violet-colored isogyres, indicating that $2V$ for red-colored light is smaller than for violet-colored light.

10) Optical dispersion

Depending on the difference of wave length, the optical orientation or character in mineral may change (Figure-11a). This phenomenon is called OPTICAL DISPERSION. The change of the orientation in optic axis may occur (optic axial dispersion). If $2V$ for red-colored light is larger than the angle for violet-colored light, the phenomenon is described as $r < v$ (Figure-11b). The reverse case is $r > v$.

11) Pleochroism and absorption

When a light passes through a medium, it is absorbed and the brightness reduced. The degree of the absorption depends on the kind of minerals, and on the wave length of used light. For example, when a material absorbs a red-colored light, the material is colored in blue under white light.

In an isotropic material, the degree of the absorption is equal in any direction. Therefore, color of the isotropic material

is equal in any direction under white light. In the case of the anisotropic material, two polarized lights advancing in one direction suffer different degrees of absorption. A light vibrating along X' shows different color from that shown by a light vibrating along Z' . This character is called PLEOCHROISM.

We can assign the color of the light vibrating along X' and Z' by taking off the analyzer and by fitting X' or Z' of the crystal with the vibration direction of polarizer.

In the case of biaxial mineral, we always describe the colors of light vibrating along the optic elasticity axes, X , Y , and Z . The color is called AXIS COLOR. We describe the axis color of Z for amphibole, for example, because the description of amphibole is always expressed with pleochrosim (Z axial color) and with extinction angle (cAZ or cAX).

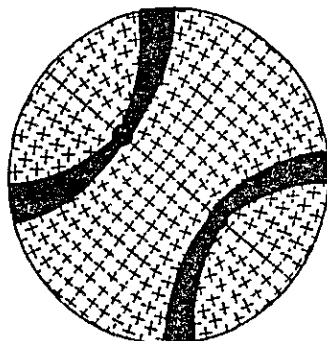


Fig.-12 One example of conoscopic figure and vibration directions of X' and Z' in each point of biaxial crystal. This crystal is cut perpendicular to Z (or X).

12) Conoscopic figure

In orthoscopic figure, parallel ray passes through perpendicular to a thin section. In conoscopic figure, however, we observe the convergent light passing through a thin section. Normally the conoscopic figure is magnified by both of bertrand

and eyepiece lenses. We use ray inclining by 30° as maximum from the central axis of microscopic tube in conosopic figure, while orthoscopic figure is observed with the parallel ray normal to the thin section. The latter is represented only by central point in conosopic figure.

The conosopic figure is composed of ISOCHROMATIC CURVES and ISOGYERS. The isochromatic curves appear due to the same reason as interference colors in the orthoscopic figure. That is; each isochromatic curve represents the trace of the same retardation. The isogyers are explained by the same phenomenon with the extinction in the orthoscopic figure. The points where vibration directions of lights coincide with those of polarizer and analyzer, are dark, being independent on the degree of retardation of them. The mode of isogyer for every section can be easily understood with the Biot-Fresnel's rule stereographically (Figure-12). MELATOPE is a point in the isogyer, which represents the direction of optic axis ($R=0$). Without melatope in conosopic figure, it is very difficult to determine the character (biaxial positive or negative) of the mineral. When $2V$ is very small, we apt to misunderstand that the mineral is uniaxial. For example, sphene has very small $2V$, and the conosopic figure resembles very much to that of uniaxial crystal.

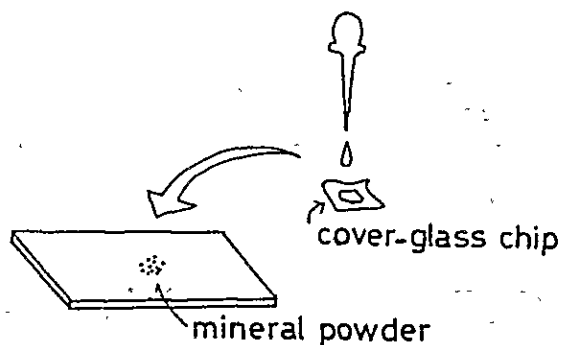


Fig.-13 Illustration of immersion method

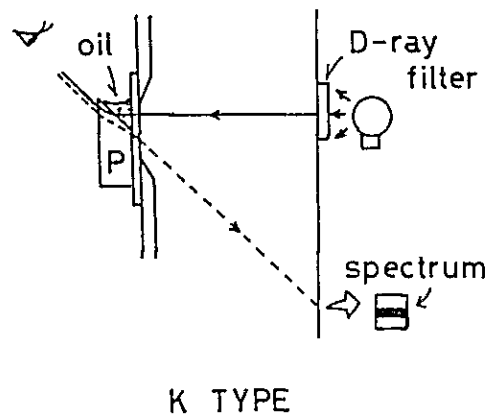
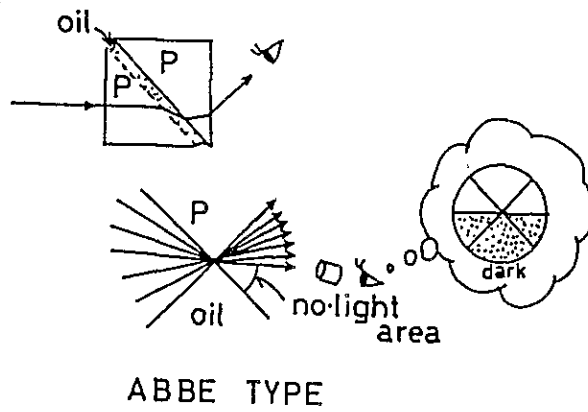


Fig.-14 Mechanism of refractometers

Immersion method

The immersion method permits measurement of the refractive index by comparing refractive index of a crystal with that of liquid with known refractive index. The goal of the immersion method is to find a liquid with known refractive index which matches that of the unknown crystal.

1) In case of optically isotropic substance

Refractive index of the optically isotropic substance does not vary in any direction, but varies depending on wave length of light used.

- (a) Fragments of the substance are powdered in a mortar. A little amount of the powder is dispersed on a glass slide.
- (b) On the chip of cover glass, immersion liquid* is dropped. The chip is turned upside down and covers the powder on the glass slide(Figure-13). The powder must be immersed in the liquid between the two glasses.

*Many immersion liquids with variable refractive indices must be prepared and measured with the refractometer (Abbe type or K type), before use. Abbe type refractometers cannot measure refractive indices larger than 1.700. The mechanisms of these refractometers are shown in Figure-14. Refractive index of the immersion liquid depends on the temperature and wave lengths of the used light.

The liquid is prepared as a mixture of some kinds of heavy liquids. Since heavy liquids are very harmful to our health, we must pay our attention to the treatment. When we wash off the liquid from the prism of the refractometer, we must use a volatile solvent such as benzene(C_6H_6), as shown in Figure-15. Do not mop up the prism by control wool! Do not use cover and slide glasses once wetted with the immersion liquid.

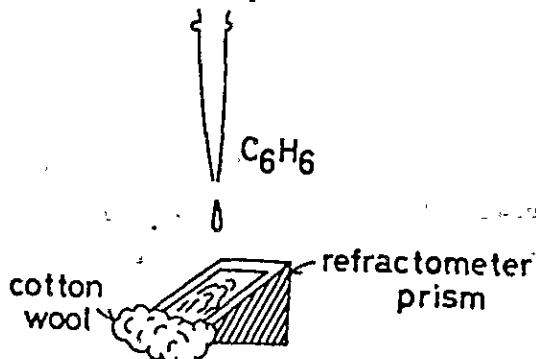


Fig.-15 Method of washing prism of the refractometer

(c) Observing the Becke's line around the unknown crystal, we can compare the refractive indices of the crystal with those of the liquid.

(d) Based on the result from (c), we try other liquids successively by the same way described in (a).

(e) Even if we cannot find the liquid whose index is coincide with that of the crystal, we can determine that the index of the crystal is between indices of two liquids, which have very-near indices.

$$n' < n < n'' \text{ or } n = (n' + n'') / 2 \pm (n'' - n') / 2$$

By this method we can determine the index down to four decimal places (0.000X), if we use monochromatic light. In general, we may determine three figures (0.00X).

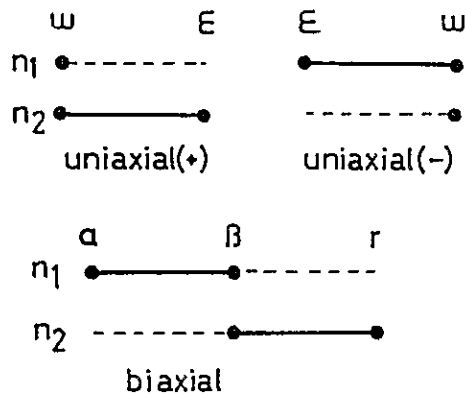


Fig.-16 Variational ranges of two refractive indices (n_1 and n_2) of uniaxial and biaxial crystals.

2) To determine the principal refractive indices ϵ and ω , or α , β and γ .

We find vibration directions, X' and Z' , of an anisotropic crystal, and we can measure n_1 and n_2 of the crystal. Turning the crystal into the extinction condition (one of vibration directions (X' or Z' ; that is, n_1 or n_2) is parallel to N-S), we observe the Becke's line.

(a) Uniaxial(positive) substance

n_1 is constant(ω), not depending on the direction of crystal, while n_2 varies from ω to ϵ . ϵ is determined as the maximum value among the observed indices of n_2 (Figure-16).

(b) Uniaxial(negative) substance

n_2 is constant(ω), not depending on the direction of crystal, while n_1 varies from ω to ϵ . ϵ is determined as the minimum value among the observed indices of n_1 .

(c) Biaxial substance

Both n_1 and n_2 vary in all directions of the crystal. The minimum value of n_1 is α , and the observed maximum value is β . On the other hand, the minimum value of n_2 is also β , and the maximum value is γ .

$$n_{1\max} = \beta = n_{2\min}.$$

A crystal which is usually black under crossed nicols (Retardation is zero) directly gives the refractive index of β . Based on the determined indices, we can calculate $2V$ of the crystal and the optic sign(see the chapter of index surface of optical principle).

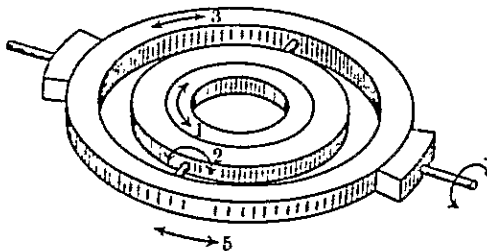


Fig.-17a Construction of universal stage. 1: inner vertical axis, 2: N-S axis, 4: E-W axis, and 5: rotation of microscopic stage.

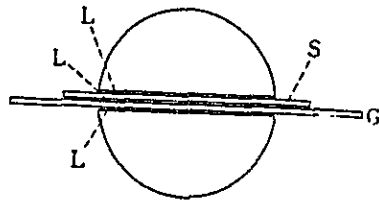


Fig.-17b Thin section sandwiched between two glass hemispheres.
 L: immersion oil or glycerin, S: thin section, and
 G: glass plate

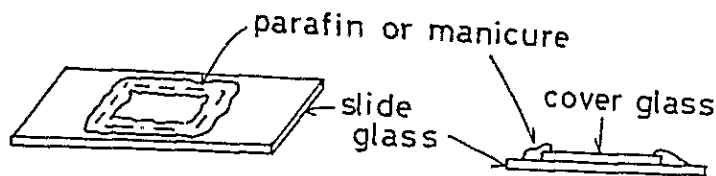


Fig.-18 Illustration of treatment of thin section to protect
 glasses from oil in the universal state.

Universal Stage

As the stage of microscope rotates within one plane, optic character of a crystal perpendicular to the stage is only able to be known. However, as the thin section rotates around more than three axes in the universal stage, we can determine the character in any direction of the crystal. The main structure of the universal stage is shown in Figure-17. There are four circles, 1, 2, 3, and 4, which can rotate independently. Thin section is put between two glass hemispheres in the center, being wetted with immersion oil or glycerine. All axes of rotation must intersect at one point at the center of the glass sphere. Available set of glass hemispheres is chosen, to obtain the refractive index near to that of the crystal in observation.

1) Setting thin section in the universal stage

As shown in Figure-18, edges and corners of cover glass on the thin section must be sealed with manicure or melted parafin to avoid damage of the glass hemisphere and to protect Canada balsam in thin section from oil. A thin section is set in the universal stages as shown in Figure-17. The centering must be done at first in the microscopic tube, and next in the inner vertical axis of the universal stage, and then in the east-west axis.

2) Measurement of the directions, X, Y and Z of a crystal

When a thin section rotates around the axis within a plane perpendicular to the microscopic tube, there are some rules as follows,

- (a) If the rotation axis is parallel to one of the optical elasticity axes, the extinction condition of the crystal is not disturbed by the rotation.
- (b) If the rotation axis is not parallel to any elasticity axis, the extinction condition of the crystal is always disturbed by the rotation.

Observing method in the universal stage is as follows,

1. Fasten the E-W axis of the universal stage parallel to the vibration direction of analyser (or polarizer).
2. Observed crystal is brought into the extinction condition by the rotation around the I.V. axis.
3. By using the E-W axis, the section is inclined into one side (the extinction is disturbed).
4. By using the N-S axis, the crystal is brought into the extinction condition.
5. By using the E-W axis again, the section is inclined into the side against the treatment in 3. The extinction condition is disturbed.

6. By the rotation around the I.V. axis, the section into the extinction condition.
7. By the E-W axis, the section is inclined into the side against the treatment of 5. The extinction out.
8. By the N-S axis, - - - .
9. By the E-W axis, - - - .

Like this, by the two rotations around the I.V. and N-S axes, the section is brought into the extinction orientation, while we check whether the extinction disappears or not by any rotation around the E-W axis.

Repeating this treatment, the extinction becomes to be not disturbed by any rotation around the E-W axis. Then, one of the elasticity axes is parallel to the E-W axis. This orientation can be read with the angles of the axes, I.V. and N-S. To determine which of the elasticity axes is parallel to the E-W axis, the test plate is inserted after turning the microscopic stage clockwise by 45° in the same condition (in the diagonal condition).

- (1) If the optic elasticity axis is X, additional condition of retardation is observed.
- (2) If the optic elasticity axis is Z, subtraction is.
- (3) If the optic elasticity axis is Y, both addition and subtraction conditions are observed during the rotation around the E-W axis.

After the determination of one elasticity axis, another axis is given by the same way (1 to 9). Last one axis is given diagrammatically on the stereogram.

3) Measurement of optic angle

According to the above method, Y axis is brought parallel to the E-W axis. After turning the stage at 45° , the section is rotated around the E-W axis. In this case, the crystal becomes

dark when the optic axis is parallel to the microscopic tube. If we observe two times of darkness during the one rotation of the E-W axis, the angle between the two darkneses is optic angle. The optic sign of the crystal is determined by the angle and the associated effect with test plate check. When we observe only one optic axis, we can determine diagrammatically the optic angle and sign, using the orientation of X or Z axis.

4) Correction of angles determined with the universal stage

Except for the case in which the refractive index of the glass hemisphere is consistent with that of crystal, the angle measured in the universal stage does not represent directly the angle of mineral. As shown Figure-19, we know the true value of angle(θ') from the measured value(θ), using the equation: $n\sin\theta = n'\sin\theta'$. Generally this correction is not necessary when the refractive index of the used glass sphere is near that of the crystal and when the inclination angle of the section is smaller than 30° .

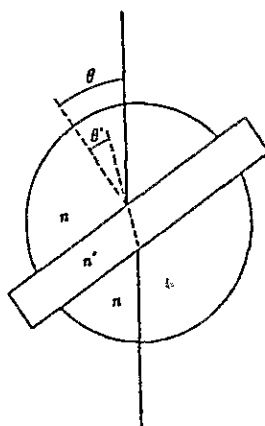


Fig.-19 Pass of light through glass hemispheres and thin section in universal stage. Refractive indices of glass and mineral are n and n' respectively.

Optical determination of plagioclase composition

Plagioclase is the most common mineral in igneous rocks. So, here, two convenient methods to determine the composition of plagioclase are explained.

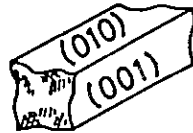


Fig.-20 Chip of plagioclase crushed in mortar.

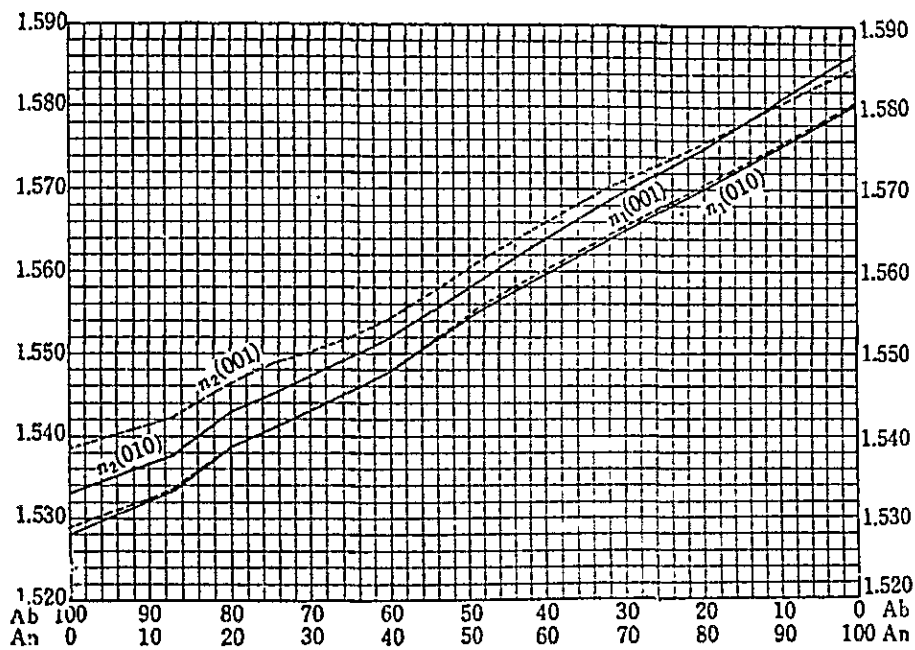


Fig.-21 Chemical composition(mol-ratio) of plagioclase and the refractive indices on cleavage planes. Dashed line is for high-temperature form. Solid line is for low-temperature form. After Tsuboi(1959); Polarized microscope, Iwanami Shoten.

1) Refractive index of n_1 on (010) or (001)

Cleavages of plagioclase are parallel to (001) and (010), as shown in Figure-20. The lower refractive index, $n_1(X')$, is nearly equal to each other on both cleavage planes (Figure-21). Using the chips surrounded by the cleavages, we can determine the composition in immersion method, without distinguishing (001) from (010). We measure the refractive index only of the fast light (X').

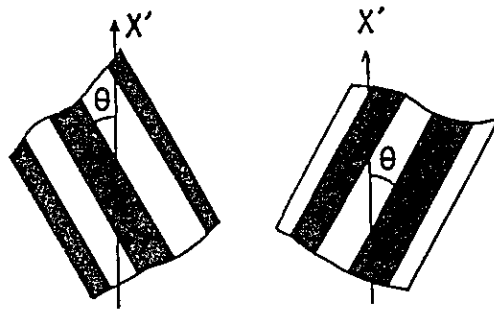


Fig.-22 Symmetrical extinction of plagioclase on the both sides of albite twin plane (010).

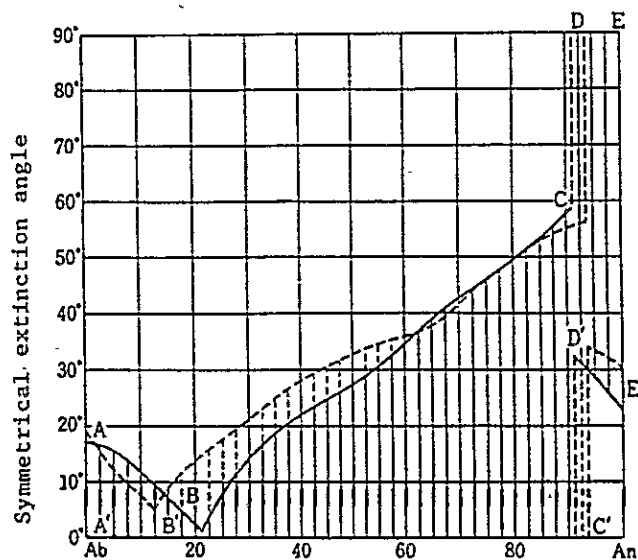


Fig.-23 Chemical composition of plagioclase (mol-ratio) and the extinction angle on the plane normal to (010) plane. Dashed line is for high-temperature form, while solid line is for low-temperature form. After Suwa et al. (1968); Proc. Japan Acad., 44, 1090-1095.

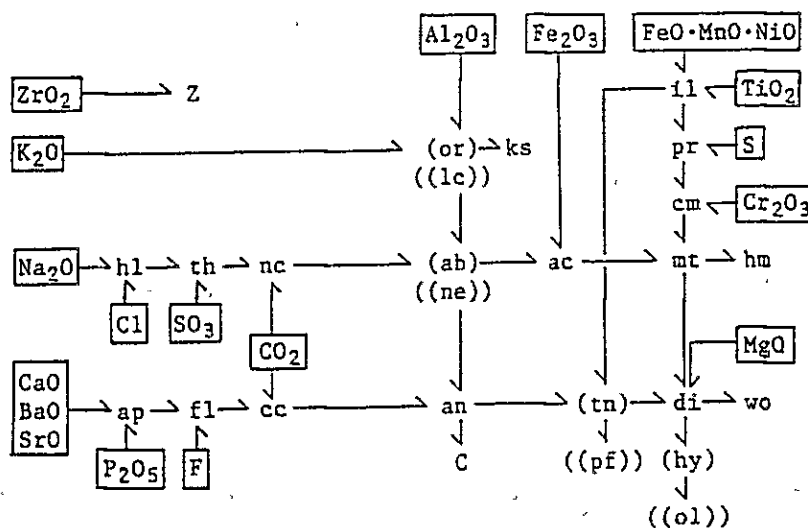
2) Maximum symmetrical extinction angle, $X'\Lambda(010)$

Any section of albite-twinned plagioclase cut perpendicular to (010) shows two sets of twin lamellae having equal extinction angle, $X'\Lambda(010)$, in both side from the trace (010). But, if the section is cut not perpendicular to (010); that is, the trace of the cleavages is not sharp, the extinction angles in both sides are not equal. The symmetrical extinction angle varies with the orientation of cutting. The maximum angle has been determined in terms of the composition. We can easily obtain the condition in which cleavage (010) is parallel to the microscopic tube and perpendicular to the E-W axis in the universal stage. After setting the cleavage parallel to the tube, we determine maximum symmetrical angle by rotations around the E-W axis and the microscopic stage.

Calculating method of C.I.P.W. norm.

There are two calculating methods of normative minerals. One is C.I.P.W. norm which is very popular, and the other is Rittmann's which is used only in Europe. The latter is very complicated and includes many human operations, and may lose the original meanings of analysis. Here calculating method of C.I.P.W. norm is explained.

Table-1 Calculation method of C.I.P.W. normative minerals



Rules of the calculating method are composed of five parts.

1) Calculation of molecular amount

(a) Results of chemical analysis are usually given in wt% of oxides. Each oxide wt% must be divided by the molecular weight, and we obtain "molecular amount" of oxides.

(b) The very small amount of MnO and NiO were added to FeO (these oxides are not treated as independent components). When BaO and SrO were analyzed, the molecular amounts are also added to CaO.

(c) There is a rule in which a molecular amount of less than 0.002 can be negligible.

2) Calculation of accessory minerals

Among the normative minerals, at first we calculate amounts of minerals which occur rarely in igneous rocks.

(a) After addition of the molecular amount of TiO_2 into the same amount of FeO, we make ilmenite ($FeO \cdot TiO_2$). In normal case, FeO is greater than TiO_2 . If TiO_2 remains, we will obtain titanite ($CaO \cdot TiO_2 \cdot SiO_2$) after calculation of anorthite in 3).

(b) After addition of the molecular amount of P_2O_5 into that of CaO by 3.3 times of P_2O_5 , we make apatite ($3(3CaO \cdot P_2O_5) \cdot Ca \cdot F_2$). We may not analyze F.

(c) When Cl_2 was analyzed, we make halite (Na_2Cl_2), adding the molecular amount of Cl_2 into the same amount of Na_2O .

(d) When SO_3 was analyzed, we make thenardite ($Na_2O \cdot SO_3$), adding the molecular amount of SO_3 into the same amount of Na_2O .

(e) When S (not SO_3) was analyzed, we make pyrite (FeS_2), adding the molecular amount of S into the same amount of O in FeO.

(f) When Cr_2O_3 was analyzed, we make chromite ($\text{FeO}\cdot\text{Cr}_2\text{O}_3$), adding the molecular amount of Cr_2O_3 into the same amount of FeO.

(g) When F was analyzed, we make fluorite (CaF_2), adding the molecular amount of F into the same amount of CaO, without being concerned about the O in CaO.

(h) When ZrO_2 was analyzed, we get zircon ($\text{ZrO}_2\cdot\text{SiO}_2$), adding the molecular amount of ZrO_2 into the same amount of SiO_2 .

(i) When CO_2 was analyzed, we make calcite ($\text{CaO}\cdot\text{CO}_2$) if the analyzed rock contains calcite, or sodium carbonate ($\text{Na}_2\text{O}\cdot\text{CO}_2$), if the rock contains cancrinite.

3) Calculation of major minerals

Using the molecular amounts of oxides which remain after the above procedures, we calculate major normative minerals.

(a) At first, we calculate orthoclase ($\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot6\text{SiO}_2$). After this, there are two cases: K_2O remains or Al_2O_3 remains. If K_2O remains (rare case), we calculate $\text{K}_2\text{O}\cdot\text{SiO}_2$. When Al_2O_3 remains, go to next step.

(b) We make albite ($\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot6\text{SiO}_2$), adding a part or all of the residual Al_2O_3 into Na_2O . When Na_2O remains, we go to the step (d).

(c) Next we make anorthite ($\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot2\text{SiO}_2$), adding a part or all residual Al_2O_3 into CaO. When CaO remains, we go to the step (e).

(d) When Na_2O remains, we make acmite ($\text{Na}_2\text{O}\cdot\text{Fe}_2\text{O}_3\cdot4\text{SiO}_2$), adding it into a part of Fe_2O_3 . Adding the residual Fe_2O_3 into part or all of FeO, we obtain magnetite ($\text{FeO}\cdot\text{Fe}_2\text{O}_3$). When Fe_2O_3 remains, we make hematite (Fe_2O_3). Normally, FeO remains.

(e) We often have the residual CaO in the step (c), and residual FeO in the step (d). These two oxides and MgO are used to make pyroxene and olivine. First, we calculate diopside

(CaO·(Mg,Fe)O·2SiO₂). Keeping the ratio of the residual FeO against MgO, we add FeO and MgO to CaO to make diopside (CaO·FeO+MgO).

(f) When CaO remains after the above procedure, we make wollastonite (CaO·SiO₂). When FeO and MgO remain, we make hypersthene ((Mg,Fe)O·SiO₂) and/or olivine (2(Mg,Fe)O·SiO₂). The presence of hypersthene or olivine, or both, depends on the amount of residual SiO₂, which is explained below. We must calculate diopside, hypersthene and olivine, the ratios, FeO to MgO, of which are equal to each other.

4) Partition of SiO₂ into the minerals

(a) SiO₂ is partitioned into the accessory and the major minerals calculated above. However, in the calculation of the final step (f) in 3), we add SiO₂ to all residues of MgO and FeO in order to obtain hypersthene. When SiO₂ remains, we get quartz.

(b) When SiO₂ is insufficient, we try to make olivine together with hypersthene, as described below. We consider the molecular amount of hypersthene as "hy" and that of olivine as "ol".

$$hy = 2(\text{residual SiO}_2) - (\text{residual (Mg,Fe)O})$$

$$ol = (\text{residual (Mg,Fe)O}) - (\text{residual SiO}_2)$$

where residuals mean the amounts remaining before making hypersthene.

(c) Even after using all of (Mg,Fe)O for making olivine, sometimes, lack of SiO₂ occurs (hy is less than zero in the above equation). In this case, we must make perovskite (CaO·TiO₂), if titanite was calculated in (a) of 3).

(d) If SiO₂ is insufficient yet, we make nepheline (Na₂O·Al₂O₃·2SiO₂) together with new amount of albite, after canceling old amount of albite, as follows.

$$ab = ((\text{residual SiO}_2) - 2(\text{residual Na}_2\text{O})) / 4$$

$$be = (\text{residual Na}_2\text{O}) - ab$$

(e) If SiO₂ is furthermore lacked, we make leucite (K₂O·Al₂O₃·4SiO₂), after canceling old amount of orthoclase. The procedure is in very rare case.

$$or = ((\text{residual SiO}_2) - 4(\text{residual K}_2\text{O})) / 2$$

$$lc = (\text{residual K}_2\text{O}) - or$$

(f) In the case of extreme insufficient of SiO₂, di or wo will be canceled, and we obtain calcium orthosilicate and olivine. Furthermore, we will make kaliophilite after lc is canceled.

Table-2 Molecular weight of C.I.P.W. normative minerals

| Normative mineral | Chemical formular | Mol.wt. | Abb. |
|------------------------|---|----------|------|
| Quartz | SiO ₂ | 60.06 | Q |
| Corundum | Al ₂ O ₃ | 101.94 | C |
| Zircon | ZrO ₂ ·SiO ₂ | 183.28 | Z |
| Orthoclase | K ₂ O·Al ₂ O ₃ ·6SiO ₂ | 556.50 | or |
| Albite | Na ₂ O·Al ₂ O ₃ ·6SiO ₂ | 524.29 | ab |
| Anorthite | CaO·Al ₂ O ₃ ·2SiO ₂ | 278.14 | an |
| Leucite | K ₂ O·Al ₂ O ₃ ·4SiO ₂ | 436.38 | lc |
| Nepheline | Na ₂ O·Al ₂ O ₃ ·2SiO ₂ | 284.05 | ne |
| Kaliophilite | K ₂ O·Al ₂ O ₃ ·2SiO ₂ | 316.26 | kp |
| Thenardite | Na ₂ O·SO ₃ | 142.05 | th |
| Halide | Na ₂ Cl ₂ | 116.91 | hl |
| Sodium carbonate | Na ₂ O·CO ₂ | 105.99 | nc |
| Acmite | Na ₂ O·Fe ₂ O ₃ ·4SiO ₂ | 461.91 | ac |
| Sodium metasilicate | Na ₂ O·SiO ₂ | 122.05 | ns |
| Potassium metasilicate | K ₂ O·SiO ₂ | 154.26 | ks |
| Diopside | CaO·(Mg,Fe)O·2SiO ₂ | - | di |
| Hypersthene | (Mg,Fe)O·SiO ₂ | - | hy |
| Wollastonite | CaO·SiO ₂ | 116.14 | wo |
| Enstatite | MgO·SiO ₂ | 100.38 | en |
| Ferrosilite | FeO·SiO ₂ | 131.90 | fs |
| Olivine | 2(Mg,Fe)O·SiO ₂ | - | ol |
| Forsterite | 2MgO·SiO ₂ | 140.70 | fo |
| Fayalite | 2FeO·SiO ₂ | 203.74 | fa |
| Calcium orthosilicate | 2CaO·SiO ₂ | 172.22 | cs |
| Magnetite | FeO·Fe ₂ O ₃ | 231.52 | mt |
| Chromite | FeO·Cr ₂ O ₃ | 223.86 | cm |
| Hematite | Fe ₂ O ₃ | 159.68 | hm |
| Ilmenite | FeO·TiO ₂ | 151.74 | il |
| Titanite | CaO·TiO ₂ ·SiO ₂ | 196.04 | tn |
| Perovskite | CaO·TiO ₂ | 135.98 | pf |
| Rutile | TiO ₂ | 79.90 | ru |
| Apatite | 3(3CaO·P ₂ O ₅) CaF | 3×336.31 | ap |
| Fluorite | CaF ₂ | 78.08 | fl |
| Calcite | CaO·CO ₂ | 100.09 | cc |
| Pyrite | FeS ₂ | 119.96 | pr |

5) Calculation of weight per cents of the minerals

Now, we obtain the molecular amount of normative minerals. Normally the amounts are recalculated in weight proportion. We multiply the molecular amount of each mineral by the molecular weight listed in Table-2. In this calculation, H_2O was omitted. The total weight of such normative minerals and H_2O is generally a little smaller than, but very close to, the total weight of oxides in original analysis. If we obtain the total weights of normative minerals, which are extremely different from the original total weight, the calculation may be wrong. We should also show the proportions of wo, en, fs, fo and fa in diopside, hypersthene and olivine.

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Wet-chemical analysis of silicate minerals and rocks

Tadato Mizota

Wet-chemical analysis is valuable as a fundamental technique of chemical analyses. This method allows us to learn the basic treatments and principles of the analysis. Especially, this is suitable to understand methods of chemical treatment of a sample and preparation of standard solutions from reagents. These are necessary to handle modern equipments for chemical analysis. Wet-analysis including gravimetry is the most precise method for all analyses of main constituents in a sample. The process of decomposition of the sample is so important for chemical analysis in the fields of mineralogy, petrology and economic geology that it has been learned through the course of silicate analysis in this lecture. The lecture treated the method of analysis on the following elements: Si, Ti, Al, Fe³⁺, Fe²⁺, Mn, Ca, Mg, Na, K, P, and H₂O content. The contents are as follows:

1. Introductory, significance of wet-chemical analysis
2. Sample preparation, rocks and minerals
3. Outline of the analysis, Main flowsheet and partial analysis
4. Details for main flowsheet, Determination of each element
5. Partial analysis
6. Standard solutions and calculation method for the analysis
7. Flame-photometry and atomic absorption spectrophotometry
8. Spectrophotometry (colorimetry)

Exercise: Units for chemical analysis

The X-ray fluorescence analysis was lectured partially.

The flowsheet of the analysis is described in detail in the part II of the volume in reference to analyses of granodiorite porphyry and K-feldspar performed in the training course of wet-chemical analysis.

X-ray powder diffraction analysis for minerals

Tadato Mizota

X-ray diffraction is utilized for identification of minerals by pattern fitting on diffraction chart, determination of precise cell dimensions of minerals, and measurement of diffraction intensities of X-ray from crystalline or sometimes amorphous materials. The method is now essential for those who are specialized in economic geology. In this lecture, special attention was paid to give understanding for diffraction geometry. Preceding to complete recognition or various application of X-ray to our field as a strong tool, we must understand the concepts of a reciprocal lattice and Ewald's reflection (diffraction) sphere. The early half of the lecture involved these and treated only X-ray powder diffraction with practical examples. It is important also to calculate unit cell dimensions and Bragg's d-values for data processing of X-ray diffraction experiment. For this purpose, we must use electric computer. The latter half of the course consisted of computer programming to calculate cell dimensions for all the crystal systems by the least squares method with h k l d-values obtained from X-ray powder diffraction experiment. PC-1500 computer was used with the BASIC language for the programming and calculation.

The contents of the lecture were given as follows.

1. Crystallographic preparation for X-ray diffraction
 1. X-ray - crystal interaction
 2. Reciprocal lattice
 3. Interplaner distances
 4. Unit cell dimensions, Least squares method by using many d-values
 5. Calculation of matrix

2. Computer programming (BASIC)
 1. To calculate area of a circle with radius R
Computer language and grammar
 2. Calculation of d-values from given cell dimensions
d-values of pyroxene
Reciprocal lattice and d^* relation
3. Programming of unit cell dimensions by the least squares method
 1. Flowchart
 2. LSUC/IGE program list
 3. Weight
 4. M and delta matrix calculation with weight
4. Standard deviations
 1. Propagation of standard deviations by calculations

The program list is shown below with the method of use. In this program, the weight for each data is neglected for calculation. NEC PC-8801 microcomputer system were introduced into the institute, after the lectures were completed. The conversion of the program into other computer system is simple, if the program is written in BASIC.

PROGRAM LSUC/IGE

```

1:REM LEAST SQU
  ARS FOR UNIT C
  ELL
2:DIM B$(6)
3:CSIZE 1
4:DIM H(30),K(30)
  ,L(30),D(30),
  DS(30),A(30,6)
  ,M(6,7),C(6),F
  $(6),E(6),X(6)
  ,S(6)
5:INPUT "SAMPLE?
";SA$
6:LPRINT "SAMPLE
---":SA$
7:B$(1)="CUBIC":
B$(2)="TETRAGO
NAL":B$(3)="HE
XAGONAL"
8:B$(4)="ORTHORH
OMBIC":B$(5)="
MONOCLINIC":B$
(6)="TRICLINIC
"
10:INPUT "CRYSTAL
SYSTEM=?";SY
12:INPUT "WAVE LE
NGTH=?";LE

14:INPUT "NUMBER
OF DATA=?";N
22:FOR I=1 TO N
24:INPUT "HKL-D?"
;H(I),K(I),L(I)
,D(I)
26:LPRINT I;"";H
(I);K(I);L(I);
D(I)
28:DS(I)=1/D(I)/D
(I)
30:NEXT I
35:LPRINT ""

```

Initial data

Sample name

Crystal system

| | | |
|---------------|---|----|
| <u>cubic.</u> | 1 | SY |
| <u>tetra.</u> | 2 | |
| <u>hexa.</u> | 3 | |
| <u>ortho.</u> | 4 | |
| <u>mono.</u> | 5 | |
| <u>tricl.</u> | 6 | |

Input

h k l d

list

A-matrix

```

40:IF SY>=2 THEN 6
  0
42:FOR I=1 TO N
44:A(I,1)=H(I)^2+
  K(I)^2+L(I)^2
46:NEXT I
48:R=1
50:GOTO 110
60:IF SY>=3 THEN 7
  0
62:FOR I=1 TO N
64:A(I,1)=H(I)^2+
  K(I)^2:A(I,2)=
  L(I)^2
66:NEXT I
67:R=2
68:GOTO 110
70:IF SY>=4 THEN 8
  0
71:FOR I=1 TO N
72:A(I,1)=H(I)^2+
  K(I)^2+K(I)*H(
  I)
74:A(I,2)=L(I)^2
75:NEXT I
76:R=2
78:GOT 110
80:FOR I=1 TO N
82:A(I,1)=H(I)^2.
  A(I,2)=K(I)^2.
  A(I,3)=L(I)^2.
84:NEXT I
85:R=3
88:IF SY=4 THEN 11
  0
90:FOR I=1 TO N
92:A(I,4)=2*H(I)*
  L(I)
94:NEXT I
96:R=4
98:IF SY=5 THEN 11
  0
100:FOR I=1 TO N
102:A(I,5)=2*H(I)*
  K(I):A(I,6)=2*
  K(I)*L(I)
106:NEXT I
108:R=6
110:LPRINT "CRYSTA
L SYSTEM=";B$(
SY)
115:LPRINT ""

```

Cubic

Tetragonal

Hexagonal

Orthorhombic

Monoclinic

Triclinic

M-matrix

```
120:FOR J1=1 TO R
122:FOR J2=1 TO R
124:MM=0
126:FOR I=1 TO N
128:MM=MM+A(I,J1)*
      A(I,J2)
130:NEXT I
132:M(J1,J2)=MM
134:NEXT J2
136:NEXT J1
```

Δ|-matrix

```
140:Q=R+1
142:FOR J1=1 TO R
144:MM=0
146:FOR I=1 TO N
148:MM=MM+A(I,J1)*
      DS(I)
150:NEXT I
152:M(J1,Q)=MM
154:NEXT J1
```

Sweep out method

```
155:IF SY=1 THEN 20
      2
160:S1=2:S2=1
162:FOR J1=S1 TO R
164:GOSUB 190
166:NEXT J1
168:S1=S1+1:S2=S2+
      1
170:IF S1=Q THEN 17
      4
172:GOTO 162
174:S1=R-1:S2=R
176:FOR J1=S1 TO 1
      STEP -1
178:GOSUB 190
180:NEXT J1
182:S1=S1-1:S2=S2-
      1
184:IF S1=0 THEN 20
      2
186:GOTO 176
```

```
190:REM "SUB190"
192:PP=M(J1,S2)/M(
      S2,S2)
194:FOR I=S2 TO Q
196:M(J1,I)=M(J1,I)
      )-M(S2,I)*PP
197:NEXT I
198:RETURN
```

Subroutine

X|-matrix

```
202:LPRINT "X(I)"
209:LPRINT ""
212:FOR I=4 TO R
214:X(I)=0
216:NEXT I
218:FOR I=1 TO R
220:X(I)=M(I,Q)/M(
      I,I)
221:LPRINT "X(";
      USING "###";I;
      ")=";USING "##
      #.#####";X(I)
222:NEXT I
225:LPRINT ""
```

Preparation to calculate
wit cell constants

```
230:IF SY>=2 THEN 2
      36
232:X(2)=X(1):X(3)
      =X(1)
234:GOTO 250
236:IF SY>=3 THEN 2
      42
238:X(3)=X(2):X(2)
      =X(1)
240:GOTO 250
242:IF SY>=4 THEN 2
      45
244:X(6)=X(1)/2:X(
      3)=X(2):X(2)=X
      (1)
245:IF SY=4 THEN 25
      0
246:IF SY=6 THEN 24
      9
247:X(5)=X(4):X(4)
      =0
248:GOTO 250
249:Z1=X(4):Z2=X(5
      ):Z3=X(6):X(4)
      =Z3:X(5)=Z1:X(
      6)=Z2
```

Calculate reciprocal and direct cell dimensions

```

250:C(1)=SQR (X(1) a*
):C(2)=SQR (X( b*
2)):C(3)=SQR ( e*
x(3))
252:C(4)=X(4)/C(2) cosa*
/C(3):S(4)=SQR sina*
(1-C(4)^2)
254:C(5)=X(5)/C(1) cosβ*
/C(3):S(5)=SQR sinβ*
(1-C(5)^2)
256:C(6)=X(6)/C(1) cosγ*
/C(2):S(6)=SQR sinγ*
(1-C(6)^2)
258:VS=C(1)*C(2)*C v*
(3)*SQR (1-C(4)
)^2-C(5)^2-C(6)
)^2+2*C(4)*C(5)
)*C(6))
260:E(1)=C(2)*C(3) a
*S(4)/VS
262:E(2)=C(3)*C(1) b
*S(5)/VS
264:E(3)=C(1)*C(2) c
*S(6)/VS
266:E(4)=(C(5)*C(6) cosa
)-C(4))/S(5)/S
(6)
268:E(5)=(C(6)*C(4) cosβ
)-C(5))/S(6)/S
(4)
270:E(6)=(C(4)*C(5) cosγ
)-C(6))/S(4)/S
(5)

```

Print out cell dimensions

```

272:F$(1)="A " :F
$(2)="B " :F$(
(3)="C " :F$(
4)="COSA":F$(5
)="COSB":F$(6)
)="COSG"
276:LPRING "UNIT C
ELL DIMS REC
IPROCAL CELL"
278:FOR I=1 TO 6
280:LPRINT F$(I);
USING "####.##
####";E(I);C(I)
282:NEXT I
290:USING
302:LPRINT ""

```

Calculate d-values

```

305:LPRINT " H K
L D(OBS) D(
CALC)"
310:FOR I=1 TO N
320:TT=(H(I)*C(1)
^2+(K(I)*C(2)
^2+(L(I)*C(3)
^2+2*H(I)*K(I)
*C(6)*C(1)*C(2)
)
322:TT=TT+2*K(I)*L
(I)*C(4)*C(2)*
C(3)+2*L(I)*H(
I)*C(5)*C(3)*C
(1)
325:DS(I)=1/SQR (T
T)
330:LPRINT USING " Print out
####";H(I);K(I) d(obs)
;L(I):USING "# d(calc)
###.####";D(I);
DS(I)
340:NEXT I
345:CSIZE 2
350:END

```


Data Input

- 1) RUN
- 2) Sample Name
- 3) Crystal System (cubic 1, tetragonal 2, hexagonal 3, orthorhombic 4, monoclinic 5, triclinic 6)
- 4) Wave length in A
- 5) number of data (N) N: less than 30
- 6)

| | | | | | |
|-------------------------------|----------|----------|----------|----------|------------------------------------|
| <u>h</u> | <u>k</u> | <u>l</u> | <u>d</u> | <u>h</u> | <input type="text" value="ENTER"/> |
| <input type="text" value=""/> | | | | <u>k</u> | " |
| <input type="text" value=""/> | | | | <u>l</u> | " |
| <input type="text" value=""/> | | | | <u>d</u> | " |

Ore microscopy

Kenichiro Hayashi

An ore microscope is a kind of polarized microscope equipped with an incident illumination system to observe polished samples of ore under reflecting light. The basic system of ore microscope is composed of a rotating stage, objective lens, eyelenses, illumination source, reflector, polarizer and analyser. The sample should be provided through final polishing with diamond paste after several steps of preliminary grindings. In this lecture, method of the sample preparation, by using equipments installed in the Institute of Economic Geology, UMSA, has been described in detail. The fundamental optical properties were lectured such as color, reflectivity, reflection pleochroism which are observed under parallel nicols, and anisotropy and internal reflection under crossed nicoles. Furthermore, to the best identification of minerals, however, various techniques including examinations of polishing hardness, morphology, cleavage, twinning, etc. are necessary. Micro-hardness test and micro-reflectance measurement can be performed by means of ore microscope attached with corresponding accessories. Vickers hardness measurement and photo-spectrometry for reflectivity measurement have been described.

The texture of ore is important to discuss the origin of the deposit, because they reflect the formation conditions of minerals or deposit and successive changes which the ore suffered. Euhedral or subhedral morphology of minerals in orthomagmatic deposit, and zoning texture, colloform structure etc. observed in vein-type deposit are of the primary mineralization. Replacement, exsolution, deformation and metamorphic textures show secondary effects of postdepositional stage.

Fluid inclusions are often seen in minerals from hydrothermal origin. These are classified into primary, secondary and

pseudosecondary types in the stage of trapping, and liquid, gaseous, polyphase and CO₂-bearing types in constituents observed under room temperature. The filling temperature which means homogenization temperature of two-phases in fluid inclusion at high temperature suggests that of formation. The theory and correction method of temperature have shown in terms of geothermometry.

The content of the lectures are listed below.

1. Introduction

Significance of ore microscopy for economic geology

2. Instrument

Mechanics and optical system: rotatable stage, lenses, illumination system, reflector, polarizer and analyser.

3. Sample preparation

Casting, grinding and polishing

4. Mineral identification

Optical properties: color, reflectivity, isotropism and anisotropism, internal reflection

Hardness and ore microscopy: polishing hardness, scratch hardness, micro-indentation hardness

Cleavage and parting

5. Quantitative measurement of reflectivity

Techniques: standard sample, background reflection, correction method

Application for determination of mineral composition and distinction of minute difference in structures

6. Hardness

Vickers hardness

7. Textures of ore minerals

Primary texture, secondary texture by replacement, secondary texture resulting from cooling

8. Fluid inclusion study

Nature and origin of fluid inclusion

Classification of fluid inclusions, gaseous, liquid, polyphase

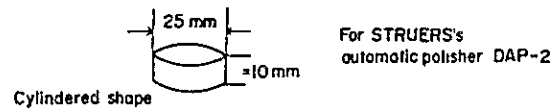
Mechanism of formation

Sample preparation and observation method

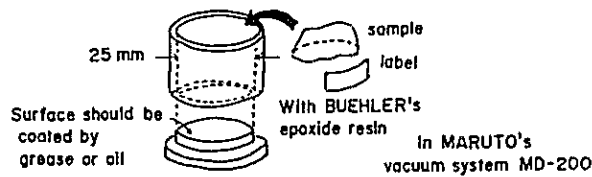
Fluid inclusion as geothermometer

P-V-T diagram of water and fluid inclusion

SIZE & SHAPE



COLD MOUNTING



COMPRESSION MOLDING

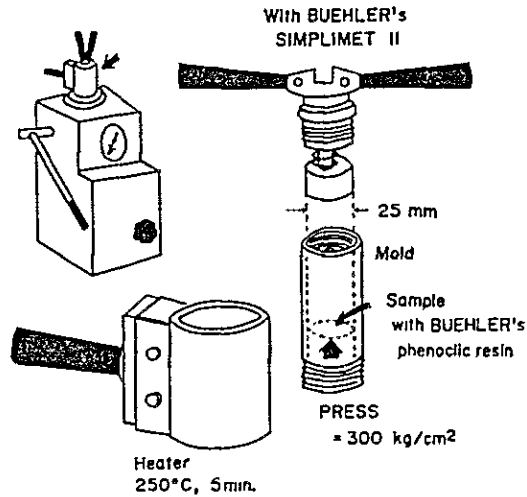
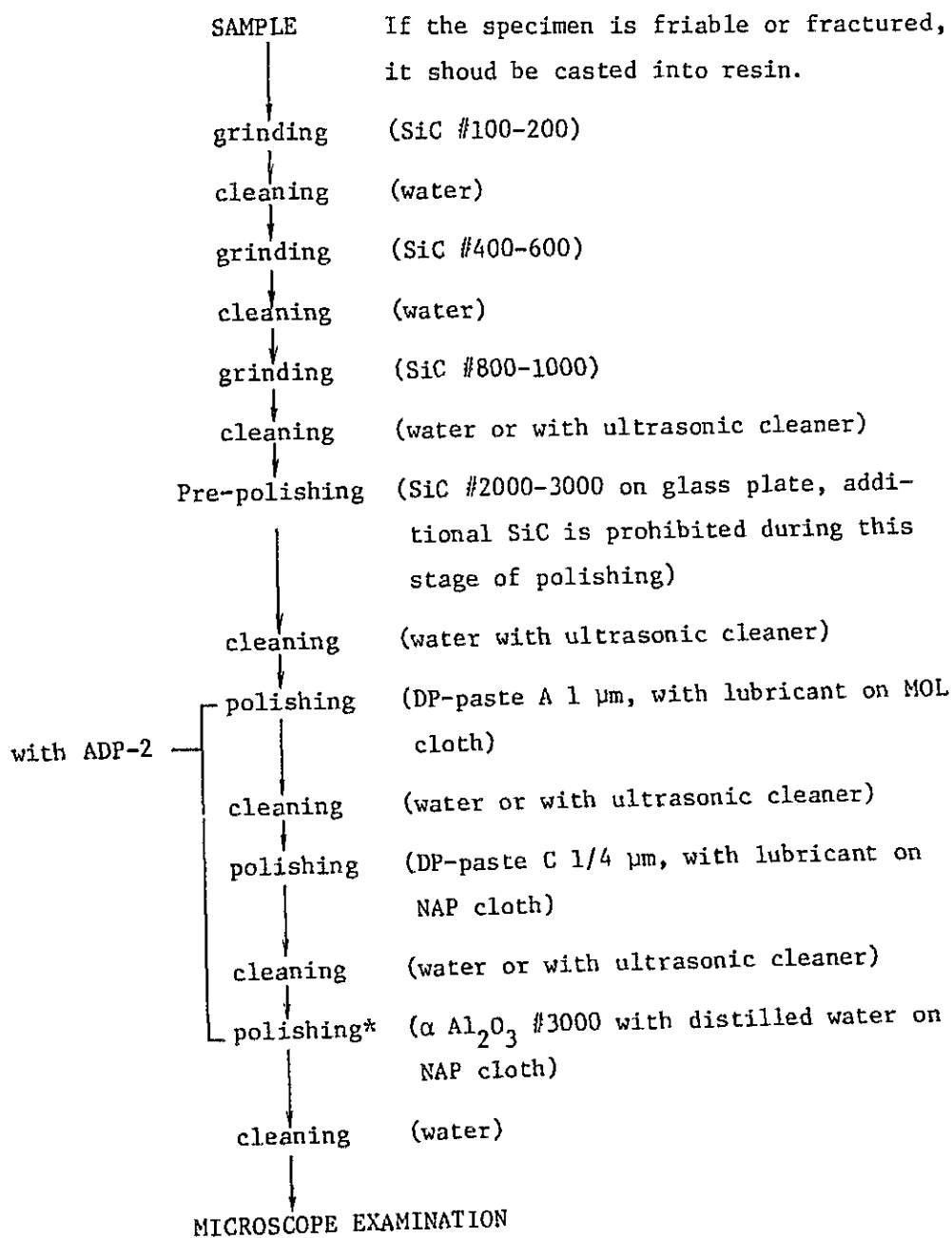


Fig.-24 Recommended method to prepare samples for ore microscope with the instruments in the Institute of Economic Geology at U.M.S.A.

The flowsheet of sample polishing for ore microscopy is shown below.



* This step is not always necessary.

Thermodynamics for Economic Geology

Shimpei Kano

The lecture has been carried out mainly on the basis of the textbook, "Thermodynamics", written by G.N. Lewis and M. Randall and revised by K.S. Pitzer and L. Brewer (1961), McGraw-Hill, New York.

Concepts in thermodynamics are important for investigators of economic geology to understand stability relations among minerals at definite conditions of formation in a deposit or to explain field observations and laboratory results on ore minerals. Modern economic geology includes also synthetic work of minerals to clarify relations among temperature and pressure of formation and chemical composition of the mineral. This enhances us also to become familiar with thermodynamics to explain the results or to plan the experimental works. The lecture consists of basic treatments in classical thermodynamics, as follows.

I Definitions

The concept of "system": closed system, homogeneous system and heterogeneous system

Extensive and intensive properties

State functions

Equilibrium, process, and reaction

II Molar properties

III The first law of thermodynamics

Mechanical equivalent of heat

The law of conservation of energy

Internal energy

Pressure and temperature

Heat and work, Enthalpy

Heat capacity at constant volume or at constant temperature

Units of energy and correlated units

- IV Application of the first law to the perfect gas
 - Work and heat of isothermal and reversible expansion
 - Work of reversible and adiabatic expansion
 - The relation between C_p and C_v

- V Heat capacities of pure substance and heats of reaction
 - Heat capacity values
 - Heat of reaction: Thermo-chemical reactions
 - Combination of equations
 - Standard state and heat of formation
 - Effect of temperature upon heat of reaction, relation between enthalpy and heat capacity, Kirchhoff's equation

- VI The Second law of thermodynamics
 - Entropy, the definition and nature
 - The law of dissipation of energy
 - Reversible and irreversible process

- VII Entropy and related equations as state function of thermodynamics
 - Entropy with volume and pressure changes
 - Helmholtz free energy
 - Gibbs' free energy
 - Spontaneous change
 - Clapeyron equation

- VIII Numerical calculation of Entropy
 - Entropy changes: fusion, vaporization, expansion and chemical reaction
 - Entropy change with temperature
 - Absolute value of entropy

- IV The third law of thermodynamics
 - Practical formulation of absolute entropy
 - Standard entropy

- X Free energy
 - Free energy of formation
 - Equilibrium and free energy

3.2.3 実 習

年度当初の計画では、湿式化学分析および顕微鏡使用についての技術指導はそれぞれ一括して集中的におこなう予定であったが、供与機材の到着が予定より遅れたため、系統的に実施されたのは湿式化学分析実験実習のみである。しかしながら、集中指導方式によらなくとも、各カウンターパートへの研究業務指導を通して、個別的な技術指導が日常的に行われてきた。以下、この日常的な指導も含めて、この1年間で行われた主な技術指導について報告する。

岩石顕微鏡

昭和57年度供与機材が昭和58年6月28日に到着するまでは、プロジェクト開始以前の派遣専門家が贈送機材とし持参し供与された岩石・鉱石兼用顕微鏡1台を用いて実習を行った。また、供与機材到着後は、複数の岩石顕微鏡および同写真撮影装置、ポイント・カウンター、ユニバーサル・ステージ、万能投影機を使用した。本実習では、プロジェクト初年度を考慮し、岩石顕微鏡下での鉱物の同定の仕方を訓練することを目的とした。以下に実施した個人指導内容と期間、および実習対象者を載せる。

昭和57年12月初旬～中旬：Oruro市San Jose鉱山地域の変質岩石を用いて、造岩鉱物と変質作用の顕微鏡下における観察。対象者：F. Saavedra。

12月初旬～中旬：鉱床学研究所所有の岩石プレパラートを用いて、一般火成岩類の造岩鉱物の顕微鏡下における観察。対象者：G. Beccar。

昭和58年1月中旬～2月上旬：Quechisla鉱山地域火成岩類の岩石プレパラートを用いて、造岩鉱物と変質作用および原岩の推定法の顕微鏡下における訓練。対象者：A. Sanchez。

3月中旬：Oruro市San Jose鉱山地域の変質岩石を用いて、変質の度合いの顕微鏡下における観察と岩石記載法の訓練。対象者：F. Saavedra。

4月上旬～下旬：Taqsesi, Mururata地域に産する花崗岩類を用いて、顕微鏡下における造岩鉱物の決定法の訓練。対象者：A. Sanchez。

6月下旬：昭和57年度供与機材の岩石顕微鏡の設置と調整・操作法の訓練。対象者：A. Saavedra, A. Sanchez, G. Beccar, F. Saavedra。

7月上旬：Oruro市San Jose鉱山産火成岩類の岩石プレパラートを用いて、ユニバーサル・ステージの調整・操作法の訓練と光学理論の解説。対象者：A. Saavedra, G. Beccar。

7月上旬：ポイント・カウンターの設置と操作法の解説。Oruro市San Jose鉱山産火成岩類の岩石プレパラートを用いて、ポイント・カウンターによる鉱物組成の決定法の訓練。対象者：A. Saavedra, G. Beccar。

8月下旬：ポイント・カウンターの操作法の解説と、Taqsesi, Mururata地域花崗岩類の鉱物組成の決定法の訓練。対象者：A. Sanchez。

9月上旬：Taqsesi, Mururata地域花崗岩類のGreisen 化作用の顕微鏡下における観察。同花崗岩中の斜長石の顕微鏡下における化学組成決定法の訓練。対象者：A. Sanchez。

10月上旬：鉱床学研究所所有のボリヴィア産火成岩類の岩石プレパラートを用いて、顕微鏡下における造岩鉱物の同定と岩石名決定の仕方の訓練。対象者：F. Saavedra。

本実習では系統的な実習が行えなかったため、顕微鏡下での鉱物の同定法の訓練が不十分であったが、岩石学的研究を行なう上で最も基本的な装置である岩石顕微鏡、顕微鏡写真撮影装置、ポイント・カウンター、ユニバーサル・ステージを調整・操作を行えるよう訓練ができた。また、この実習の一部は室内研究活動の中で活かされ、第二部に業績論文として掲載されている。

(担当者：中田)

湿式化学分析

鉱床学研究の対象には、鉱石のみならず、鉱床を胚胎する火成岩、堆積岩等、地殻構成物質全般が含まれる。ここでは、地殻構成物質の代表的なものとしての珪酸塩鉱物及び岩石を湿式化学分析し、化学分析の基礎的手法を習得させることを目的とした。この方法は、珪酸塩の熔融分解法を含み、容量法、重量法、炎光光度法、分光光度法をも含ませることにより、応用範囲も広く、化学分析全般にわたる知識・技術が習得できると考えられる。この実習の中で、1) 化学分析室の整備、装置の設置、2) 化学天秤の使用法の実習 3) イオン交換・蒸留水製造装置設置と使用法の実習 4) 分光光度計の実習 5) 原子吸光及び分光光度計の実習等が行われた。

1) 化学分析室の整備

化学分析室2室とストックルームの試薬保管について機材の到着以来カウンターパートと日本人専門家が分担して作業を進めた。分析室は2室となりあってあり、以下の主要装置が配置された。

- ドラフト2 ヤマト
- 主分析台 ヤマト
- 原子吸光炎光分光光度計 日立
- 分光光度計 日立
- イオン交換・蒸留水製造装置 ヤマト・オートステル
- マッフル炉 ヤマト
- その他滴定台、サイドテーブル、試薬棚など

2) 化学天秤の実習

天秤室に設置を終えた後8月3日、4日にわたり、天秤の使用法の実習を行った。天秤は、ザウターマクロ型2台及び島津直示天秤1台で、いずれも感度0.1mgである。

3) イオン交換・蒸留水製造装置 8月4日再生法の説明と採水のコック操作の実習

4) 湿式化学分析の実習

すべての分析室関係の装置の設置付帯工事の終わった9月19日から6名のカウンターパートと分析実験を開始した。試料は、Oruro市San Jose 鉱山近くのSan Pedro石切場の石英斑岩及びCerro Viscachaniのカリウム長石を用いた。標高約3,300mのLa Paz市Cota Cotaの鉱床学研究所においては、水の沸点が約85℃ということもあって、普通海水面レベルで行われている分析法が、そのまま実行できるかどうか疑問があった。しかし沸点が低いことにより沈殿熟成に長時間を要すること、及び、LPGガスバーナーを用いては高温が達成できず、電気炉を用いざるを得ない点を除き分析は可能であった。7名のカウンターパートのうち2名はカリウム長石を他の4名が石英斑岩の同じ試料を3個分析した。結果と方法については本報告書第二部に詳述した。この実習の中で、Mnについては分光光度計を用い、Na, Kについては原子吸光・蛍光光度計を用いて分析した。

(担当者: 溝田)

粉末X線回折計

本装置は、昭和56年度供与機材として納められたものである。鉱物のX線回折図形による同定、格子定数の測定、回折X線強度の測定を行い、鉱石や岩石の鉱物学的性質を明らかにするための装置である。このように高度な精密機械を長年にわたり保守管理してゆくためには、カウンターパートが、装置の原理を良く理解し管理が適正に継続されなくてはならない。本装置の角度分解能は、 $\pm 0.01^\circ$ 以内でなければならない。1983年4月7日本装置を用いて零点調整法についての実習を行った。

(担当者: 溝田)

示差熱及び熱重量分析

本装置は、主として鉱物の高温における熱的性質の解明を行うものである。研究所の移転の前DTA装置の取扱い、特に試料ホルダーの洗浄保守等の管理について実習・指導を行った。DTA-TGについては設置とTGの調整を行った。

(担当者: 溝田)

マイクロコンピュータ NEC PC8801 システムによるデータ解析

粉末X線回折の講義の中で、鉱物の格子定数の計算及び回折面間隔の計算を扱い、機材到着前にPC1500コンピュータを用いて、BASICプログラミング法、及び、格子定数の最小二乗法による計算のプログラミング実習を行った。また、PC8801システム及びPC1500システムBASIC文法書の英訳を行いカウンターパートに配布した。

(担当者: 溝田)

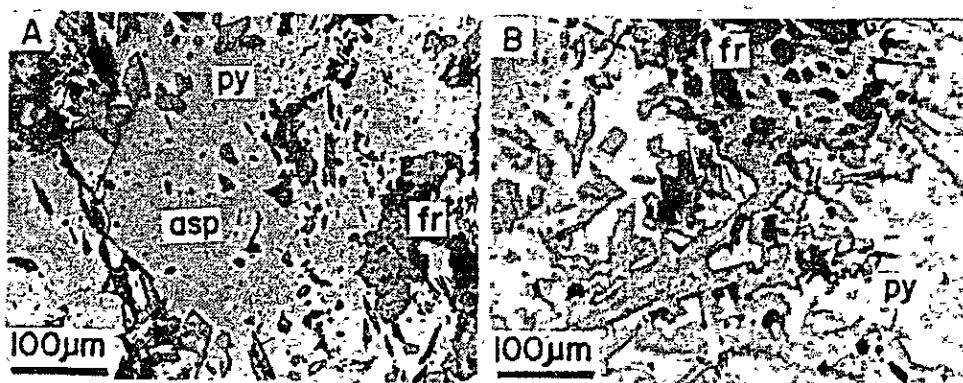
鉍石頭微鏡

鉍石にどのような鉍物が含まれているか、鉍物間にどのような共生関係があるか、各鉍物の晶出順序はどうか、またどのような鉍石組織が認められるか等は鉍床の成因を考慮する場合に重要である。これらは顕微鏡下で観察する他確認の方法がない。また種々の分析手段を使用して資料を出す場合、鉍石全体の中でどの部分を分析しているのかを知る必要がある。さもなくば、分析値自身がどの程度の精度であり、またどのような意味を有するかが不明確となる。それを避けるには、試料を分析に先立ち顕微鏡下で観察するのが最良の方策であろう。この点で鉍石頭微鏡は鉍石を研究対象とする場合、最も基本的な装置であり、鉍床学研究所の職員であれば鉍石の検鏡に精通する必要がある事は言うまでもない。

鉍石頭微鏡は基本的には岩石観察用の偏光顕微鏡に落射照明を付け反射光下で鉍石の表面を観察する装置である。昭和57年度供与機材のうち日本光学製顕微鏡X T P及びY B Pにはいづれも落射照明装置が装備されているのでこれらを使って指導を行った。主に林が担当した。Ore Microscopy と題する講義の中で理論的な指導を系統的に行っているものの、本プロジェクトの計画に再び、本格的な実習指導は昭和59年3月頃から予定している。

従って鉍石頭微鏡の実習は個人指導となった。Sr. F. Saavedraは、現在、San Jose鉍山 J 脈を研究中で、鉍石頭微鏡をある程度使いこなせる力を有するに至った。元来顕微鏡観察には十分な経験が必要であり、大学カリキュラムの中でこの方面の実習がない現状では短期間での検鏡力のレベルアップは困難を伴う。更に、ポリヴィアではSan Jose鉍山に代表される様に、鏡下での性質がほぼ似かよった種々の硫酸鉍物を多産する(第1図)。このため、顕微鏡下でのみ同定は難しい。これら鉍物を鏡下である程度同定できる様になるには、通常の鉍物群に対するよりも高度の知識が必要であるため、更に充実した実習用試料を準備中である。

(担当者: 林)

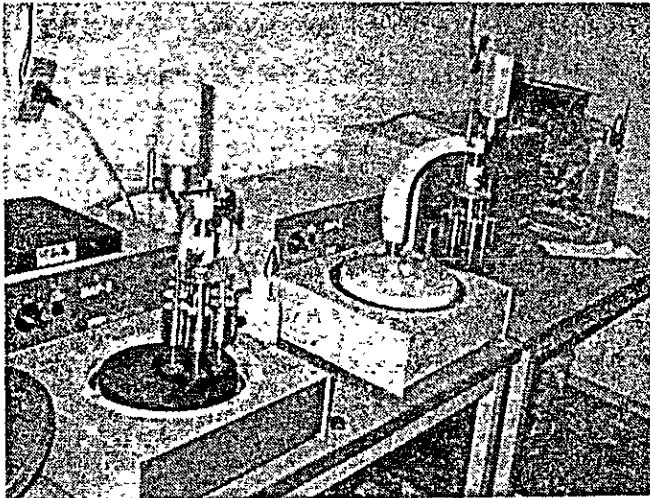


第1図 San Jose 鉍山 J 脈産鉍石の顕微鏡写真
A: J脈, -380mレベル B: J脈, -380mレベル py: 黄鉄鉍, asp: 砒鉄鉍, fr: フランケ鉍。
第1図 San Jose 鉍山 J 脈産鉍石の顕微鏡写真

検鏡用試料作製

岩石及び鉱物を顕微鏡下で観察する場合、検鏡に先立ち観察用に試料を準備しなくてはならない。一般の岩石の場合は一面を平滑にした後スライドガラスに貼りつけ、その後光を透過するようになるまで薄くする。これを透過偏光顕微鏡（岩石顕微鏡）で観察するわけである。一方光を通さない不透明鉱物（主に鉱石）の集合より成る試料（鉱石に代表される）の場合は一面を平滑にした後、光を反射させるために研磨を行う。その後反射偏光顕微鏡（鉱石顕微鏡）で観察を行う。地質学の場合、研究試料の顕微鏡観察は不可欠であるため、これら検鏡試料を作る技術は最も基本的な事と言える。

昭和57年供与機材の中にはこのために使用する機器及び消耗品類が多数含まれており、これらを使用して指導を行った。主に使用機器は岩石切断機、平面研磨機、準備研磨機、鉱石研磨機（第2図）などであるが、この他にホットプレート、樹脂真空浸漬機、超音波洗浄機などを適宜使用した。実習の担当は岩石顕微鏡用の薄片作製の場合中田、また鉱石顕微鏡用の研磨片の場合は林が中心となって行った。これらは実習講義型式は取らず、その時々個人指導を



第2図 研磨機DAP-2を使用して研磨片の最終仕上げを行っている様子。

した。

実習者は、O. Sanjines, A. Sanchez, G. Beccar, F. Saavedraである。また鉱床学研究所には試料作製のための職員が不在のため、運転手のJ. Castilloがこれらの作業をする事が多い。従って彼に対しても指導している。延時間は30時間程度である。

特に研磨片を作る場合、その作製方法は試料の性質、使用する機器及び材料によって若干異なる必要がある。また最良の方法というものはなく、製作者自身が工夫を試みそれぞれの方法をあみ出しているようである。推奨する方法はOre Microscopyと題する講義の中で触れた。カウンターパートは、この方法で通常の試料であれば、まづまづの状態の物を作製し

ている。しかし剝離性を有する試料（ポリヴィア産鉍石には硫酸鉍物のたぐいが多数含まれているので、この様な試料は多い）などは表面を再度に亘り樹脂などで固める必要があるが、その場に応じた工夫をできる所まではまだ到達していない。表面の状態の悪いまま最終研磨にかけ、研磨布を傷めてしまう事が数回あった。

検鏡試料作製は手の汚れる仕事である。これに類する仕事を現在一部のカウンターパートは余り好まない様であり、自分から積極的にはなかなかやらない。理学部地球科学科には、専門の試料作製職員が居る様で、安易にそちらへ頼む事が多いが、でき上って来た物は良いとはいえない。これは最終研磨に問題があると思われる。鉍床学研究所で作製した物との差が目瞭然なので、今後とも自分で手を汚して作るべく指導していくつもりである。

（担当者：林）

流体包有物

熱水鉍床より産する鉍物中には、その鉍物が晶出する際周囲の流体を取り込んだ流体包有物（初生包有物）が多数認められる。更に、鉍物晶出後割れ目に沿って形式されたものもある（二次包有物）。初生的には周囲の流体を取り込んだ流体包有物も、その後の温度の低下に伴い、水の臨界条件下で、室温では2相（液相と気相）に分離する（2相包有物）。また上記の他に、NaClなどの結晶が認められる場合（多相包有物）や、CO₂を含むこともある。2相包有物の場合、これを加熱すると最終的に液相又は気相1相となりこの温度（充填温度）を測定し、必要な補正を施すとその包有物が生成した時の温度、すなわち包有物を含む鉍物の生成温度を推定することができる。これが流体包有物地質温度計の原理である。

また鉍物を晶出させた流体は種々の濃度で塩（主にNaCl）を含んでいる事が知られている。流体包有物を冷却し凍らせた後、温度を回復させ氷点を測定すると、包有物中の塩濃度を推定することができる。これは鉍物を生成した流体の性質を知るために重要である。

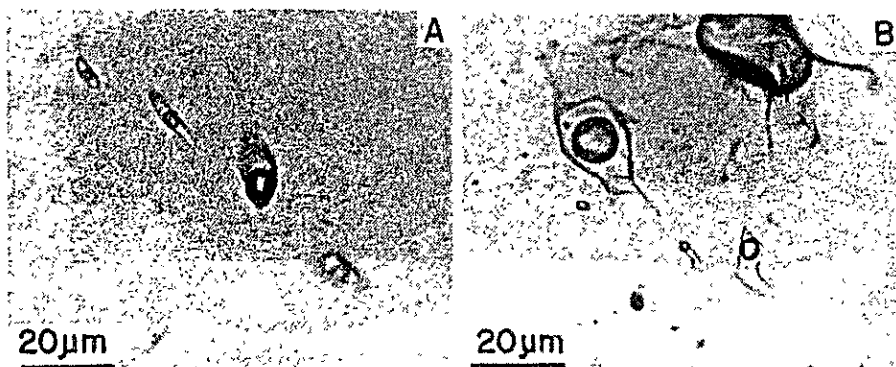
以上の2点が流体包有物を研究する上で重要なポイントである。本研究所にある加熱ステージ及び冷却ステージを使って実習を行った。担当者は南部及び林。現在流体包有物の研究を専ら行っているのはIng. H. Villenaであり指導は主に彼に対して行っている。南部専門家の指導の下、VillenaはSan Jose 鉍山産試料を使って充填温度測定のパターを出している。測定実験を行う場合、測定値にどの程度の誤差があるかを知っておく必要がある。林はこの目的のために加熱ステージの温度更正を行った。方法は融点の知られる純金属In, Sn, Pb, 及び試薬過マンガン酸カリウムの融点を測定することによった。その結果Pbのデータは少しおかしいが、実際の温度よりも測定値が高目に出ている事が明らかとなった。400℃前後で50℃程度の誤差を有している。これは加熱ステージの構造によるもので、加熱室中で試料がむき出しのまま加熱されているので、空気の対流などの影響が無視できないと考えられる。現在Villenaと共に加熱ステージの改良を検討中である。

また充填温度の測定値に生成圧力に対する補正をしないと真の生成温度を求めることができない。現在の所、San Jose 鉱山の鉱脈群は浅所生成と考えているため、圧力補正を行わなくとも特に問題はないという結論に達しているもの一応この点念頭に置く指導を行った。

なお、冷却実験（氷点測定）に関する指導は現在までのところ行っていない。

San Jose 鉱山 J 脈産石英中の流体包有物の写真を添付した（第 3 図）。

（担当者：林）



第 3 図 San Jose 鉱山 J 脈産石英中の流体包有物

A, B とも J 脈, 380 m レベル。気相と液相より成る典型的な 2 相包有物である。

科学写真技術

研究の成果を公表する場合、写真を用いて説明すると相手に与える印象は大きい。地質学の場合、写真は特に重要視されており、人に論文を配る時などもコピーよりも印刷刷刷が有効であり、それは他分野よりも写真を多用する点にも一つの原因があろう。また口答で研究成果を発表する時でも、スライドを用いて視覚に訴えれば、聴衆の理解度が増す点は言うまでもない。

地質学分野で我々が必要とする写真技術には大きく 3 がある。第 1 に通常の現像、焼付技術（カラー写真のこの技術は素人にはやや困難なので、できなくてもかまわないと思われる）。第 2 に顕微鏡写真の撮影技術。第 3 にスライド作製技術である。

これらのうちスライド作製については溝田が、及び顕微鏡写真の撮影を林が中心となり指導した。実習者は Ing. A. Saavedra, Ing. O. Sanjines, Ing. A. Sanchez, Ing. H. Villena, Sr. G. Beccar. 及び Sr. F. Saavedra である。使用機器は供与機材のカメラ類、暗室用品、顕微鏡写真撮影装置である。

使用する感光材料、薬品はそれぞれの目的に応じて使い分けられる。まずこれを衆知させる様務めた。カウンターパートは感光材料と薬品の組み合わせなど、まだ十分に理解していないが、鉱山調査の際に撮影した写真の現像焼付等は自らやれるようになった。

顕微鏡写真撮影の場合、光源は通常 タングステン又はハロゲン封入タングステンランプである。これら光源とフィルムとの組合せを考慮する必要がある。白黒写真の場合、大きな影響はないが、緑色フィルターを使用した方が良い。一方カラー写真の場合は光源の色温度と通常のカラーフィルムのそれとが全く異なるため、そのまま撮影すると色が適正に表現されない。このため光源の色温度をカラーフィルムに合わせるのに青色フィルターを使用する。タングステンタイプフィルムを使用すれば問題はないが、ポリヴィアでは見当らない。露出時間は自動の顕微鏡写真撮影装置（日本光学：A F X - 3 5 A）であるため通常の試料であれば問題はないが、直交ニコル下での撮影など特殊条件下ではある程度経験に頼り補正する必要がある。この点、カウンターパートはまだ十分に理解していない様子である。これは何回か失敗をくり返さないとならないうら。と身につかないだろう。

（担当者：林）



写真1 岩石顕微鏡で岩石薄片を観察中のIng. R. Santivañes 鉱床学研究所長

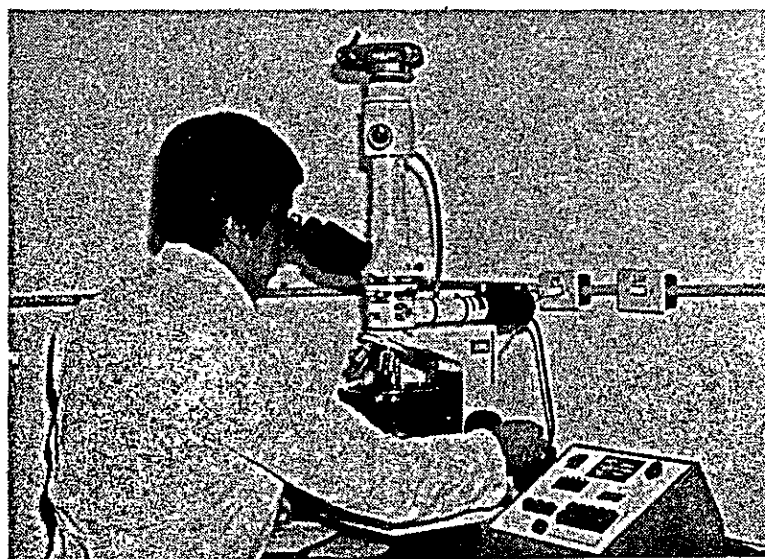


写真2 岩石顕微鏡によるモード分析にポイントカウンターを使用中のIng. H. Villena

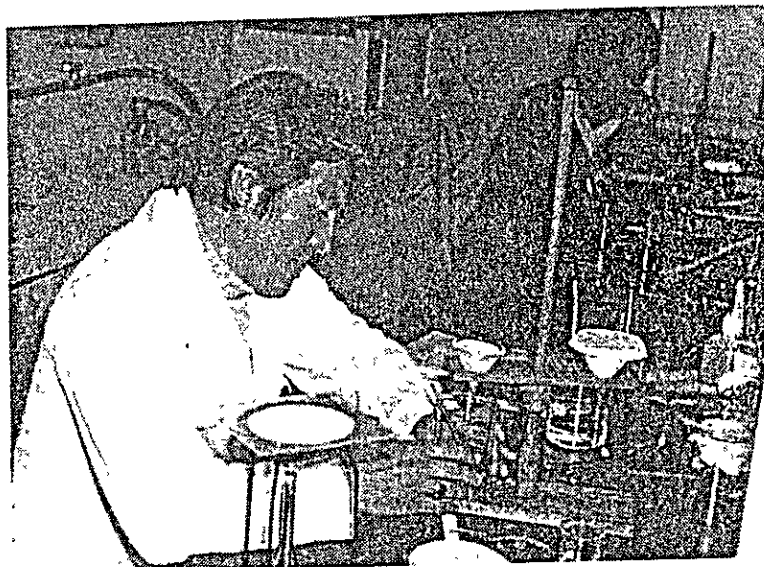
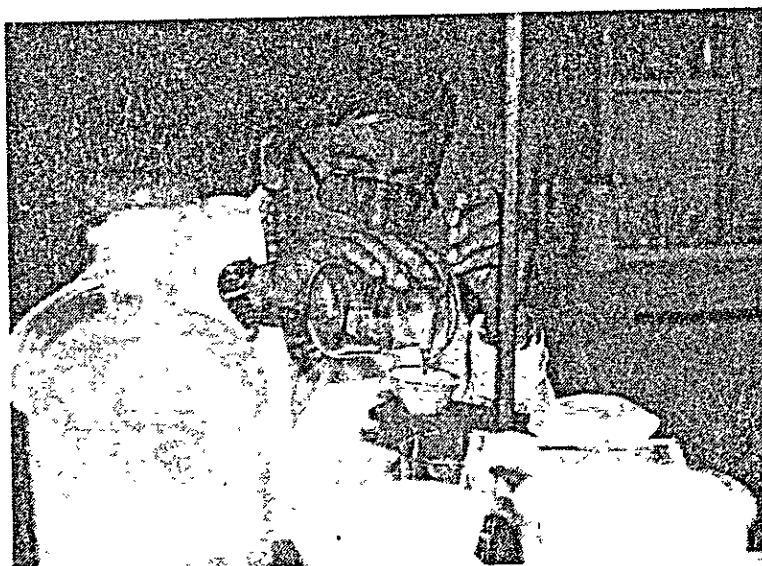


写真3 湿式化学分析実習中のカウンターパート

A. マグネシウム分離を終えた Ing. O. Sanjines



B. ろ過操作中の Ing. H. Villena



C. 沈殿洗浄操作中の Ing. E. Soria と指導中の溝田専門家



D. しゅう酸カルシウムの分離ろ過を行う Sr. F. Saavedra

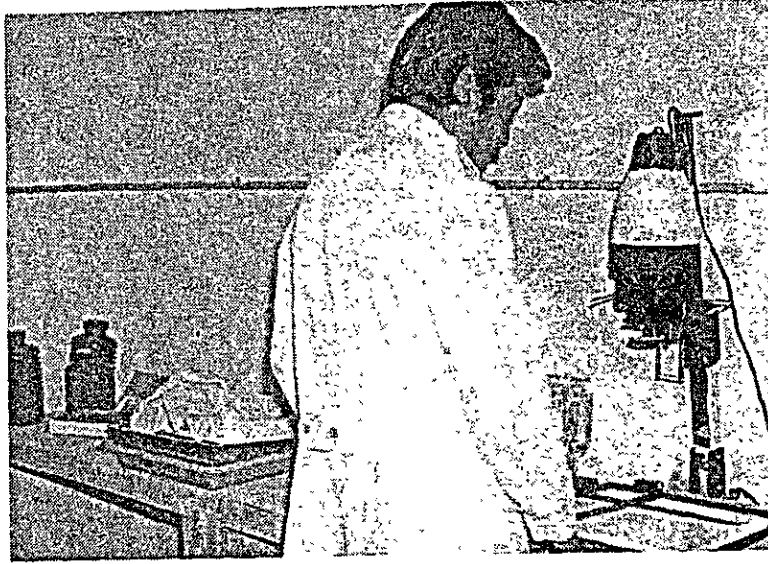


写真4 科学写真技術実習を行う Ing. O. Sanjines

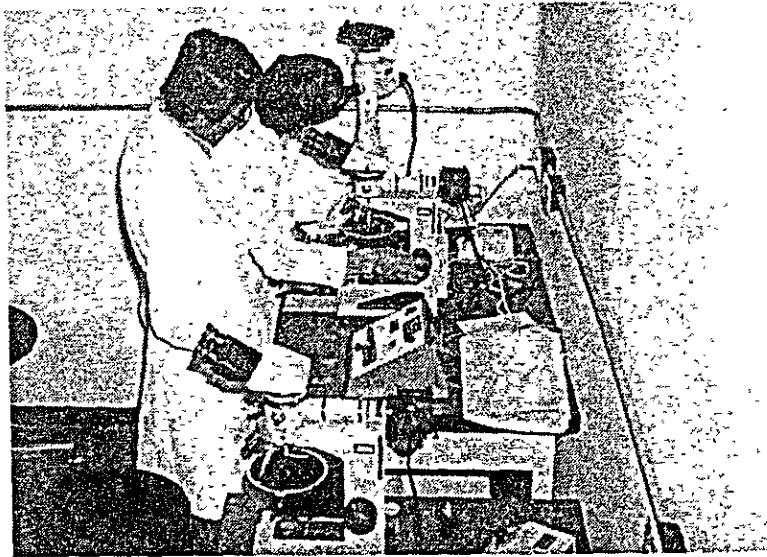


写真5 鉱石顕微鏡実習を行う Ing. A. Saaveda と Ing. H. Villena

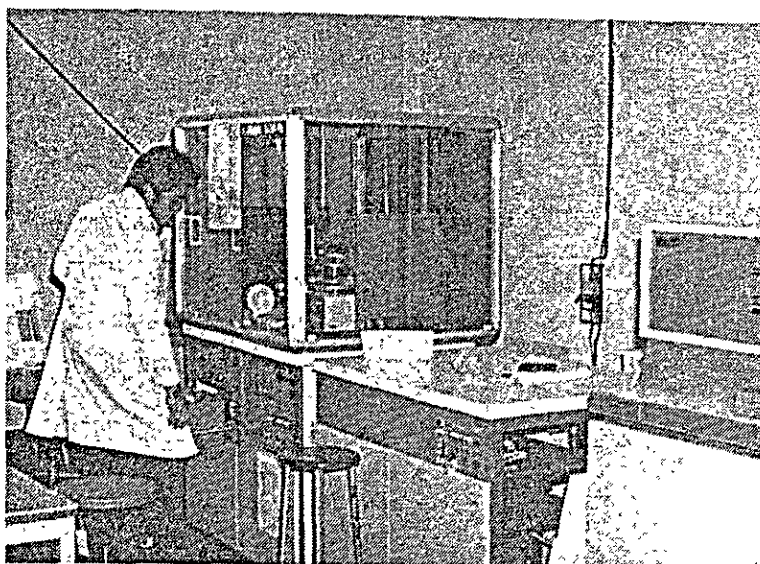


写真6 粉末X線回折実験

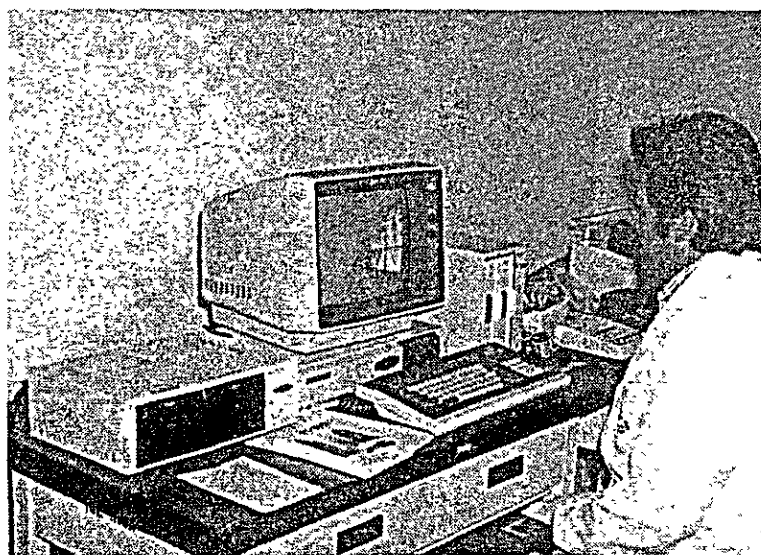


写真7 マイクロコンピュータNEC, PC8801の実習

3.2.4 研究活動

野外調査

昭和58年5月21日：Huayna Potosi (Songo)花崗岩類の野外調査と試料採集（中田，A. Sanchez）。試料採集地点は第1図に示すとおりである。Huaya Potosi花崗岩は，La Paz近郊のMilluni 鉍山の鉍化作用をもたらした火成活動の産物であり，鉍床の成因を考える上で本花崗岩の成因を研究することは重要である。この調査では，花崗岩体の周縁部から内部に向かって，花崗岩の鉍物組成がどのように変化するかを調べる目的で行われた。本研究はA. Sanchezと共同研究中である。

昭和58年9月3日：Taqesi-Mururata地域の花崗岩類の野外調査と試料採集（中田，林，A. Sanchez）。本花崗岩体中には，San Francisco 鉍山など錫・タングステンの鉍脈が発達しており，鉍脈の周囲の岩石はGreisenizationをこうむっている。また，本花崗岩体はZoned Plutonを示しており，マグマの組成と鉍化作用に関係が認められる。この花崗岩体の研究は，A. Sanchezが数年前から手がけていたものであり，中田との共同研究結果は本報告書第二部に掲載されている。

昭和58年9月6日～9日：チリ国境沿いの第四紀火山岩類の野外調査と試料採集（中田，E. Soria）。鉍床の成因を考える上で，新しい火山岩類を調査・記載することは，鉍床学分野における岩石学の基礎知識を鍛練する上で重要である。このため，チリ国境沿いのSajama火山を中心に野外調査が行われた。試料採集地点は第1表に掲げてある。また，Sajama火山についての岩石記載結果は，本報告書第二部に掲載してある。

昭和58年9月26日～28日：Cochabamba州Independencia (Cerro Sappo)のアルカリ岩岩脈の野外調査と試料採集（鹿野，中田，林，G. Sandi）。本火成岩岩脈は中生代に堆積岩（古生層）に貫入したものである。岩脈中のSodaliteは国外に輸出されるボリヴィア国鉍産資源の1つである。調査では，Sodaliteの母岩であるNephelinite (nepheline Syanite)を採集する計画であったが，新鮮な岩石は残っておらずnatrolite粘土鉍物などに変質している。本研究は継続中である。

第1表 岩石学野外調査採集試料一覽

SAMPLING LOCALITIES AND SAMPLE DESCRIPTION

Sajama Volcano

| | | | |
|------------|------------|------------|--------------------------------|
| SN83090701 | 18°07'20"S | 68°56'45"W | Hornblende dacite(lava) |
| SN83090702 | 18°07'10"S | 68°56'00"W | Biotite dacite(lava) |
| SN83090703 | 18°07'15"S | 68°55'45"W | Biotite dacite(lava) |
| SN83090704 | 18°07'20"S | 68°55'40"W | Biotite dacite(lava) |
| SN83090705 | 18°07'25"S | 68°55'40"W | Biotite dacite(ignimbrite) |
| SN83090706 | 18°07'30"S | 68°55'50"W | Biotite dacite(lava) |
| SN83090707 | 18°07'25"S | 68°55'50"W | Biotite dacite(lava) |
| SN83090708 | 18°07'30"S | 68°56'10"W | Hornblende dacite(lava) |
| SN83090801 | 18°06'90"S | 68°58'10"W | Augite hornblende dacite(lava) |

Punuta Volcano

| | | | |
|------------|------------|------------|--------------------------|
| SN83090802 | 18°01'20"S | 68°57'45"W | Pyroxene andesite(lava) |
| SN83090803 | 18°00'15"S | 68°57'40"S | Porphyritic dacite(lava) |
| " 3' | " | " | Aphyric andesite(lava) |

Canasita Volcano

| | | | |
|------------|------------|------------|------------------------------|
| SN83090804 | 17°55'55"S | 69°10'40"W | Pyroxene andesite(lava) |
| SN83090805 | 17°48'20"S | 69°17'50"W | Biotite rhyolite(ignimbrite) |

Anallajchi Volcano

| | | | |
|------------|------------|------------|--------------------------|
| SN83090601 | 17°59'05"S | 68°48'20"W | Porphyritic dacite(lava) |
|------------|------------|------------|--------------------------|

Sorkhe Volcano

| | | | |
|------------|------------|------------|--------------------------|
| SN83090902 | 17°24'30"S | 69°17'10"W | Porphyritic dacite(lava) |
|------------|------------|------------|--------------------------|

Tertiary

| | | | |
|------------|------------|------------|-------------------------|
| SN83090901 | 17°28'15"S | 69°19'20"W | Pyroxene andesite(lava) |
|------------|------------|------------|-------------------------|

Huayna Potosi(Songo) granite complex

| | | | |
|------------|-----------------|--|------------------------------|
| SN83052101 | | | Graywacke(Cancaniri F.) |
| SN83052102 | | | Biotite granite(Chloritized) |
| SN83052103 | | | Biotite granite |
| SN83052104 | shown in figure | | Biotite granite |
| SN83052105 | | | Biotite granite |
| SN83052106 | | | Biotite granite(Chloritized) |
| SN83052107 | | | Muscovite granite |

Progreso II, Cerro Sappo

| | | | |
|------------|------------|------------|---------------------------|
| SN83092701 | 16°53'05"S | 67°53'00"W | Sodalite-carbonate rock |
| - 20 | " | " | Natrolite-cancrinite rock |

室内研究実験(岩石学)

Oruro市San Jose鉱山地域岩石の変質と鉍化作用についての岩石顕微鏡的研究(中田, F. Saavedra, G. Beccar)。昭和58年3月初旬に採集された火成岩類を中心に、顕微鏡下での岩石記載が行われた。また、岩石記載の結果をいかに図上で表現するかを検討した。この結果は、F. SaavedraのUMSA提出用論文の元となった。第2図にSan Jose鉱山の北に分布する花崗斑岩の顕微鏡写真を載せた。この花崗斑岩の全学化学組成とカリ長石の化学組成は、溝田専門家の指導の下に湿式化学分析法で検討されている(本報告書第二部)。

Oruro市San Jose鉱山Itos地区の鉍脈に伴う母岩の微細構造研究。本研究はA. Sanchezが中心になって研究しており、中田が協力した。母岩の節理方向を多量に測定し、ステレオ図上で検討された。

Taquesi花崗岩類の岩石学的研究(A. Sanchez, 中田)。A. Sanchezが採集した花崗岩試料と化学分析値を基に、岩石顕微鏡下での観察を行い、本花崗岩類と鉍床をつくったGraisenizationのメカニズムについて検討した。また、A. Sanchezには、この研究結果をまとめる際に、科学論文の書き方について指導した。この成果は第二部に掲載してある。

Oruro州Sajama火山の岩石学的研究(中田, E. Soria)。チリ国境沿いのSajama火山から採集された岩石試料を基に、岩石顕微鏡と蛍光X線分析装置を用いて、本火山岩の岩石学的記載が行われた。第3図に顕微鏡写真を載せた。また、空中写真を用いて火山の形態や火山岩の噴出様式も検討された。この研究結果は第二部に掲載されている。

Cochabamba州Progreso II鉱山産アルカリ火成岩類の岩石学的研究(鹿野, 中田, 林, G. Sandi)。Cochabamba州Independencia北方にあるアルカリ岩(nephelineiniteかnepheline syenite)岩脈の岩石を用いて、岩石顕微鏡での観察とX線粉末回折装置による造岩鉍物の検討がなされた。第4図にsodaliteと母岩の顕微鏡写真を示す。また第5、6図にはX線粉末法によるsodaliteとnatroliteの回折図形を示した。本研究は継続中である。



第2 a 図 Oruro市San Jose 鉱山地域 San Pedro に分布する biotite granodiorite の顕微鏡写真 (lower nicol のみ)。左上に sanidine の大きな結晶が観察される。横幅は約 2 mm。



第2 b 図 同上の crossed nicols での顕微鏡写真。



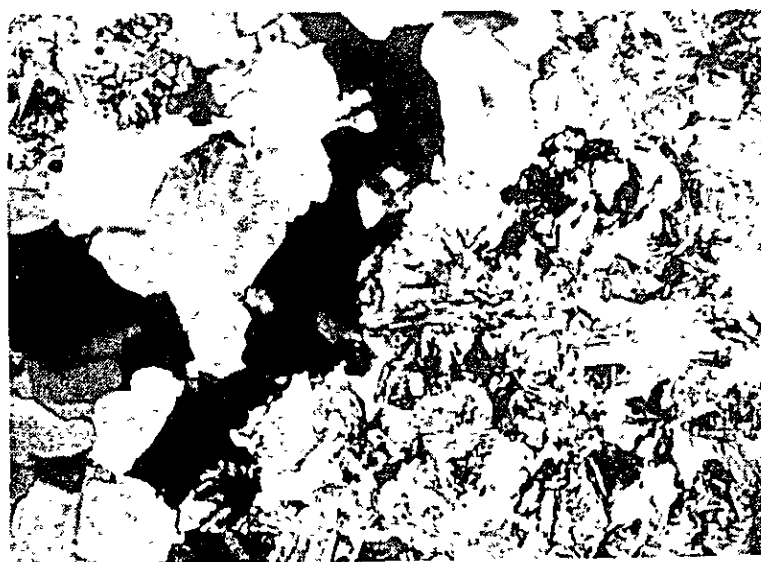
第3 a 図 チリ国境沿いにあるSajama火山岩類 (biotite dacite) の顕微鏡写真 (lower nicolのみ)。中央に菱形のsphenoidの斑晶が観察される。横幅は約2mm。



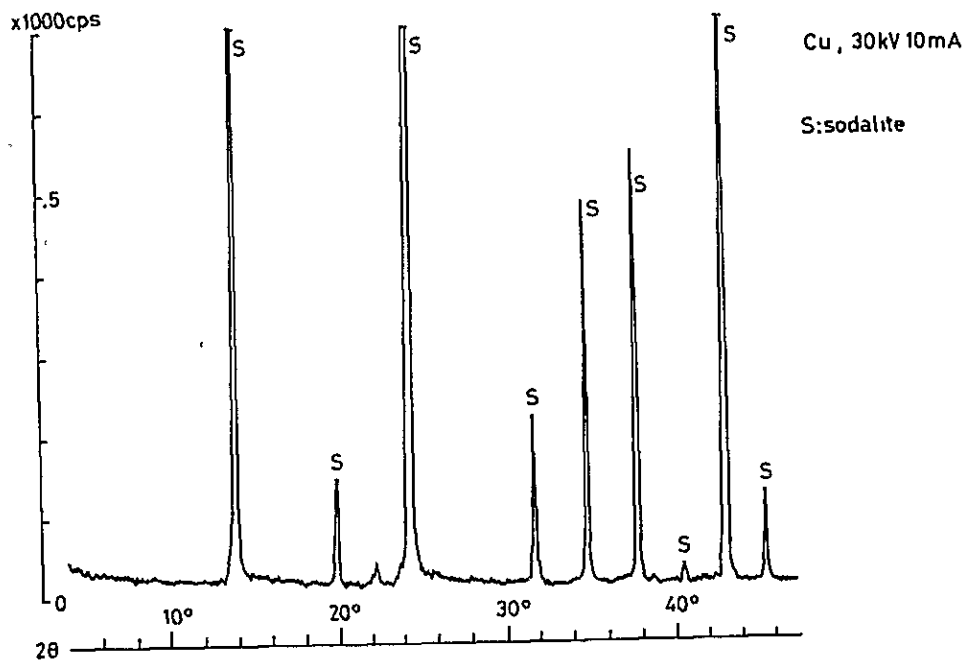
第3 b 図 同上のcrossed nicolsでの顕微鏡写真。石基はガラス質でspherulitic textureを示している。



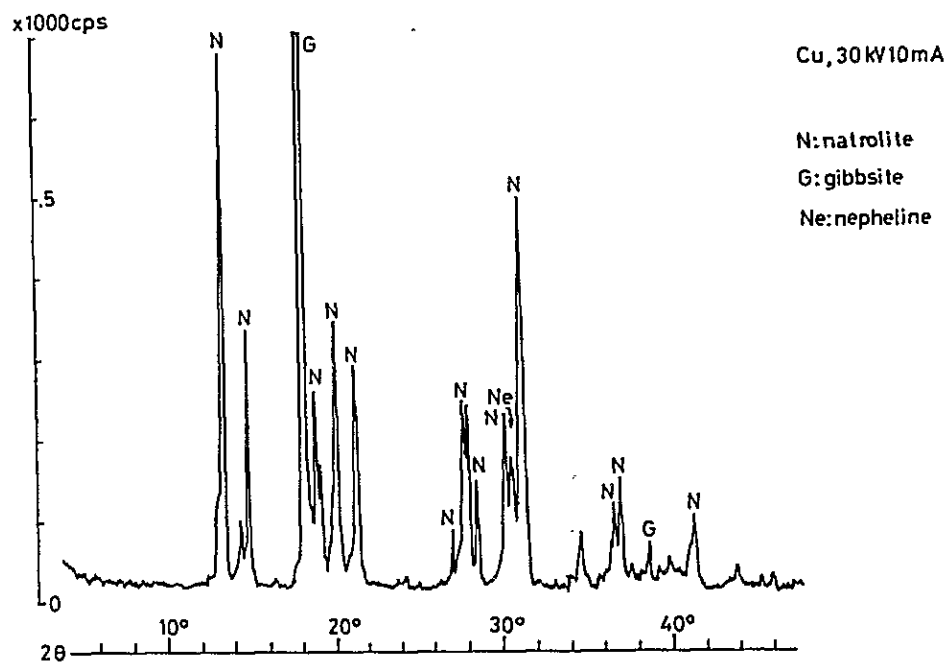
第4 a 図 Cochabamba 州 Progreso II 鉱山産 sodalite の顕微鏡写真 (lower nicol のみ)。左上が sodalite, 右下が carbonate mineral。両者の境界に針状の粘土鉱物 (?) が生じている。横幅は約 2 mm。



第4 b 図 Cochabamba 州 Progreso II 鉱山産アルカリ岩岩脈の顕微鏡写真 (crossed nicols)。放射状の微少結晶集合体は natrolite。板状に見える比較的大きい結晶は cancrinite。横幅は約 2 mm。



第5図 SodaliteのX線粉末回折図形(Cu-K α)。分析者：上原誠一郎(九州大学)。



第6図 ア カリ岩のX線粉末回折図形(Cu-K α)。分析者：上原誠一郎(九州大学)。