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# ASPECTS TO THE GEOCHEMISTRY OF CHROMIUM, COBALT, NICKEL AND ZINC

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*Pris 2 kronor*

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## Contents.

## Preface.

In this paper, I shall give a summary of my principal minor element determinations on Swedish minerals, rocks and soils, *viz.* those determinations that may to some extent elucidate the geochemistry of chromium, cobalt, nickel and zinc. Part of these data are new, part of them have been collected from earlier papers (P. H. Lundegårdh 1946 and 1947 a—b). A statistical analysis of the data given reveals a number of interesting trends, which may in certain cases serve as keys to the petrological history of the rocks considered. Of course, further investigations are in many cases necessary. Thus, for instance, the early Archaean leptites and granites of easternmost Central Sweden are by far overrepresented when compared with their equivalents from other parts of Central Sweden.

The investigations the results of which will be now published, have been performed at the Royal Agricultural College of Sweden, in its institute of plant physiology (head: Professor H. Lundegårdh), and at the Geological Survey of Sweden (director: Professor P. Geijer). Most rocks and soils analysed have been collected by the writer. Further, a number of samples were received from Dr. B. Asklund, Dr. E. Fromm, Dr. I. Hessland, Mrs. Ebba Hult De Geer, Prof. E. Ljungner, Dr. G. Lundqvist, Prof. N. H. Magnusson, Dr. N. Sundius, Dr. E. Åhman and Dr. O. H. Ödman. For valuable aspects to the division of the Gotho-Karelian rocks, I should like to express my gratitude to Dr. W. Larsson. For financial support, I am indebted to Statens naturvetenskapliga forskningsråd, Statens tekniska forskningsråd and the Geological Survey of Sweden.

## Abbreviations.

If nothing else is stated, concentrations are given in parts per million (g/ton). M means the arithmetic mean of a series of samples, n means number of samples in each series considered. $\Sigma$ should be interpreted as sum. Thus $\Sigma(\mathrm{Mg,Fe}) = \mathrm{Mg} + \mathrm{Fe}$.

# I. Introduction.

Chromium, cobalt, nickel and zinc belong to the minor elements of the crust. According to earlier geochemical data, *chromium* should be the most important member of this group. F. W. Clarke and H. S. Washington (1924) thus proposed 370 as a mean concentration in igneous rocks. V. M. Goldschmidt (1938) reduced this figure to 200. The same average concentration was obtained for clayish and sandy sediments (Goldschmidt 1938). Swedish rocks and soils are, however, by far lower in chromium, as evident from S. Landergren's (1943, 1948 a) and the writer's investigations. Even the crust as a whole can be suspected to contain less chromium than was suggested by Goldschmidt (see Chapter IV).

On the other hand, the *cobalt* content of the crust was once underestimated — Clarke and Washington (1924) proposed 10 as an average of igneous rocks. Goldschmidt (1938) gave 40, a figure that seems to be more reliable, especially in view of Landergren's and the writer's investigations.

The medial *nickel* content of igneous rocks was determined as 200 by Clarke and Washington (1924). J. H. L. Vogt (1931) reduced this figure to 100. The same concentration was proposed by Goldschmidt (1938). It should be considered as a maximum value. The average quotient Ni : Co of the crust seems, indeed, to be lower than 5 : 2 (*cf.* P. H. Lundegårdh 1946 a, p. 142).

The average *zinc* concentration of the crust has been estimated at 100 (P. H. Lundegårdh 1946, p. 143; 1947 b, pp. 1 and 18—19).

The principal factors regulating the distribution of the four elements considered are their coordination numbers. The oxygen coordination of $Cr^{3+}$, $Co^{2+}$ and $Ni^{2+}$, which illustrate the common valencies in Nature, are *6-fold*, whereas the coordination of $Zn^{2+}$ may be either *4-fold* or *6-fold* (see P. H. Lundegårdh 1947 b, pp. 2—3). This means that the structures of the feldspar minerals do not receive the four elements considered.

If we exclude certain sulphide, hydroxide and carbonate ores, chromium, cobalt, nickel and zinc are concentrated to spinels and to magnesium-iron-silicates (*femic* minerals), such as biotite, amphibole, pyroxene and olivine ($Mg^{2+}$, $Fe^{2+}$ and $Fe^{3+}$ are all 6-coordinated). The highest concentrations of chromium and nickel will be found in silicate rocks comparatively high in magnesium and low in iron. On the other hand, silicate rocks rich in iron and poor in magnesium most frequently lack these two elements.

V. M. Goldschmidt (1945, pp. 3—4) has interpreted the last-mentioned phenomenon as follows: »In such cases when different ions of similar size and of the same charge (valency) substitute each other during the crystallization of minerals from cooling igneous rocks, the sequence for entrance of the various ions into the crystal lattices is generally the sequence of decreasing bond strength. The electrostatic bond strength, in cases of identical electric charge, is inversely proportional to the squares of the interionic distances: thereby the smallest ion is bonded preferentially. Thus magnesium ions are bonded before the somewhat larger ferrous ions, and these again in preference to the manganous ions. In those cases where electronic bonds are present besides ionic bonds, the integral sum of bond strength is decisive: therefore, nickel is concentrated in the earliest fractions of magnesium silicates from magmas, even though nickel and magnesium have virtually identical ionic radii; and chromium spinels crystallize before other spinellide minerals because of the contribution of electronic bonding in the minerals of trivalent chromium.

Ionic substitution in minerals from magmas takes place not only between ions of identical charges having similar radii, but also in a great number of cases where ions of similar radii but different charge are concerned. In such cases the ion with higher ionic charge is captured in the crystal lattice in preference to the ion which has a lower charge. A very well known example is the series of plagioclase feldspars which are characterized by the substitution of divalent calcium for univalent sodium. — — — In such cases the sequence of entrance into the crystals is again the sequence of bond strength, the highly charged ions being captured by the crystal lattice, the lower charged ions being admitted only when the supply of the normal lattice components is nearly exhausted.»

Goldschmidt's interpretation implies that, in crystallizing silicate melts, magnesium ($Mg^{2+} = 0.65$ Å[1]), chromium ($Cr^{3+} = 0.64$ Å) especially, and nickel ($Ni^{2+} = 0.69$ or $0.70$ Å) are concentrated to the introductory, zinc ($Zn^{2+} = 0.74$ Å) and divalent iron ($Fe^{2+} = 0.75$ Å) to the final stages of differentiation, whereas cobalt ($Co^{2+} = 0.72$ Å) is more uniformly distributed to various stages. Trivalent iron ($Fe^{3+} = 0.67$ Å) is primarily not very frequent in the early, basic products of fractional crystallization, owing to the low degree of oxidation of these (see Landergren 1948 a). However, when present, trivalent iron should be captured simultaneously with chromium.

A kinetic reasoning on the distribution of elements, with temperature as an essential factor, has been employed by F. E. Wickman (1943). Wickman defines the *E-value* of a certain ion as »the energy required in order to move an ion from a position with a certain coordination number to a neighbouring position with a different coordination number». E is thus the *activation energy of migration* of the ion under consideration (Wickman 1943, p. 373). Elements that are captured in early magmatic differentiates, such as chromium, should have large E-values (1943, p. 385). On the whole, Wickman's conclusions agree with those of Goldschmidt as given above.

In the structures of femic minerals free from trivalent metals, such as olivine, nickel replaces magnesium directly, whereas chromium needs a supply of univalent ions if electrostatic equilibrium is to be attained after a replacement. These univalent ions should have a radius similar to that of chromium. Further, they should be 6-coordinated. Even if such ions exist, *viz.* lithium ($Li^{+} = 0.60$ Å), it seems probable that most chromium, together with some oxygen, further some aluminium and/or magnesium and/or iron, in this case separates as spinel

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[1] The crystal ionic radii given in this paper are those of L. Pauling (1940).

(picotite, chromite *etc.*). In femic minerals with trivalent metals, such as augite, chromium can of course enter the structure directly.

In a recent paper (P. H. Lundegårdh 1947 b), I gave a number of data of zinc as a component of various Swedish rocks and soils. I pointed out that zinc accompanies magnesium as well as divalent iron, and that, owing to its high volatility, it is concentrated to late magmatic differentiates (*op. cit.*, pp. 4 and 19 *ff.*). I further pointed out that the distribution of zinc in various sediments is governed by the differentiation working during all normal transports and depositions of eroded matter (*op. cit.*, pp. 28—29). This differentiation implies that, *inter alia*, quartz and quartz-feldspar sediments — sand and sandstones, are low in zinc, whereas clays and clay slates are rather high in the metal mentioned.

In two earlier papers (P. H. Lundegårdh 1946 a—b), I have studied the distribution of chromium, cobalt and nickel in certain magmatic ores and rocks. I could test the validity of Goldschmidt's above rules as applied to the distribution of these elements (1946 a, p. 149, and 1946 b). Of the various consecutive differentiates of each special magma examined, the early ones have concentrated chromium and nickel, whereas the middle ones are rather low in these elements. The late differentiates lack chromium and nickel. Cobalt is as a rule uniformly distributed. In the latest differentiates analysed, however, even this metal vanishes (together with magnesium).

Similar results have been obtained by R. L. Mitchell in collaboration with L. R. Wager (Wager and Mitchell 1943: rocks of the Skaergaard intrusion, Greenland) and S. R. Nockolds (Nockolds and Mitchell 1948: some Caledonian plutonic rocks).

## II. Methods.

With only few exceptions, the analytic data given in this paper are derived from solid samples and by means of quantitative arc spectrography (see P. H. Lundegårdh 1946 a, pp. 11—24, and 1947 b, pp. 9—14). Using the highest attainable intensity of the arc light,[1] the analytic sensitivity is chiefly a function of the sensitivity of the photographic plates used. As different kinds of plates were exposed by the writer from time to time, at first Agfa plates, later Ilford plates, varying sensitivities of each special element investigated were obtained.

Most samples analysed are *general samples* — in the case of rocks mixtures of disintegrated, fresh specimens from various (at least 20) parts of homogeneous outcrops, in the case of soils mixtures of at least 20 representative local samples.

Many samples (clay sediments, gneisses and granites especially) were added a certain amount of pure sodium chloride (Dutch vacuum salt), corresponding to 20,000 Na, in order to prevent volatilization of $SiO_2$ and depress the inevitable combustion of the electrode material used, here carbon. This operation is

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[1] Projection of the picture of the arc on the slit of the spectrograph by means of only one lens (*moderate* magnification).

necessary if reproduceable data for zinc are to be obtained, although the analytic sensitivity will be simultaneously lowered (*cf.* P. H. Lundegårdh 1947 b, pp. 10—11). The accuracy of the chromium determinations are also favoured on addition of sodium chloride.

## III. Chromium, Cobalt, Nickel and Zinc in Minerals.

In the introduction, I pointed out that the essential amounts of chromium, cobalt and nickel in crystallizing natural silicate melts are separated together with magnesium and iron. Further, I mentioned that chromium especially, and nickel, are enriched in *early magmatic* minerals crystallized from melts high in magnesium and low in iron, whereas the distribution of cobalt does not display such a decided trend. In final magmatic minerals extraordinarily high in iron and low in magnesium, even cobalt seems to vanish, however.

Recently, Mitchell analysed minerals separated from Scottish Caledonian igneous rocks (Nockolds and Mitchell 1948). The main minerals of these rocks *inter alia* show the following concentrations (femic and salic minerals given in order of relative age from oldest to youngest):

| | Cr | Co | Ni |
|---|---|---|---|
| Augite (n = 2) | 1,500—2,500 | 30—70 | 90—200 |
| Hypersthene (n = 1) | 200 | 100 | 300 |
| Hornblende (n = 8) | 150—800 | 20—40 | 80—150 |
| Biotite (n= 13) | 25—800 | 15—40 | 30—150 |
| Muscovite (n = 1) | 50 | < 2 | < 2 |
| Plagioclase (n = 9) | < 2—15 | < 2—30 | <2—20 |
| Potash feldspar (n = 11) | < 2 | < 2 | <2— 5[1] |

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[1] 10 samples show Ni < 2.

As could be expected, the feldspar minerals are almost free from chromium, cobalt and nickel (*cf.* p. 4).

In 1945, Wager and Mitchell published a number of minor element analyses of olivine and clinopyroxene separated from the basic plutonic rocks of the Skaergaard intrusion, Greenland (early minerals given first):

| | *Olivine* from | | |
|---|---|---|---|
| | Gabbro-picrite | Olivine-gabbro | Hortonolite-ferro-gabbro |
| Cr | 1,000 | < 2 | < 2 |
| Co | 100 | 100 | 100 |
| Ni | 1,000 | 400 | 10 |
| $Fe_2SiO_4$ | 190,000 | 370,000 | 600,000 |

| | *Clinopyroxene* from | | |
|---|---|---|---|
| | Olivine-gabbro | Middle gabbro | Hortonolite-ferro-gabbro |
| Cr | 400 | < 2 | < 2 |
| Co | 40 | 60 | 40 |
| Ni | 80 | 50 | < 2 |
| $FeSiO_3$ | 190,000 | 360,000 | 500,000 |

Here, the differentiation of the three trace metals considered is by far more distinct than in the Scottish Caledonian igneous rocks. The Skaergaard minerals, however, have developed by fractional crystallization of one single magma portion.

The high concentration of chromium in olivine separated from gabbro-picrite seems to be due to minute inclusions of picotite or some other chromium spinel in the fissures of the mineral. Separations of such inclusions are very intricate. Part of the chromium content may, however, be situated in the olivine structure, possibly together with lithium (see p. 5).

A few years ago, I gave some additional data of the distribution of chromium, cobalt and nickel in gabbro minerals (P. H. Lundegårdh 1946 b). The three samples analysed were all separated from the ultra-basic gabbro at Grovstanäs, Central Roslagen, Sweden (see P. H. Lundegårdh 1943 and 1947 a). This rock is extraordinarily low in chromium (see Table 7). The analyses run as follows (earliest mineral given first):

| | Olivine from peridotite | Clinopyroxene from ultra-basic norite | Titano-magnetite from ultra-basic norite |
|---|---|---|---|
| Cr | 6 | 5 | $< 0.5$ |
| Co | 250 | 130 | 50 |
| Ni | 550 | 50 | $< 0.5$ |
| | $Fe_2SiO_4$ = 200,000 | $FeSiO_3$ = 300,000—350,000 | $Fe_2(Fe,Ti)O_4$ = 990,000 |

In order to study the compositional influences upon a certain mineral as originated by variations of the conditions during its development, I separated grains of iron garnet from: I. bands of garnet-hornblendite in Svecofennian (p. 17) diorite (late basic magmatic differentiate; Table 6) from Solö in Central Roslagen, and II. veined gneiss (high-metamorphic clay slate, Table 12) near Drevviken S of Stockholm (for comparison, data of the mother rocks are given in parentheses).

| | Cr | Co | Ni | Zn |
|---|---|---|---|---|
| I | 0 (0) | 15 (25) | 0 (0) | 500 (80) |
| II | $< 1$ (4) | 50 (50) | $\leqslant 1$ (80) | 700 (200) |

These figures do not only display the lack of chromium and nickel in late magmatic minerals (I), they also suggest a similar geochemical differentiation in metamorphic sediments (II).

The high concentration of zinc in the garnet analysed is in excellent agreement with the rules of geochemical differentiation given in Ch. I. Further evidence of the enrichment of zinc in late-magmatic compounds will be found in Goldschmidt 1938 (p. 81). Goldschmidt here summarizes N. H. Brundin's unpublished investigations on the distribution of zinc. Of various minerals separated from igneous rocks, biotite should be especially high in this element. Recently, I could confirm Brundin's experience (P. H. Lundegårdh 1947 b,

p. 19 *ff*.). Thus, the biotite of a grey Svecofennian gneiss-granite with a total amount of 150 zinc contains as much as 600 zinc, whereas its amphibole shows Zn = 400 (P. H. Lundegårdh 1947 b, p. 21).

## IV. Chromium, Cobalt, Nickel and Zinc in Rocks and Soils.

### A. Previous Work.

The rules governing the distribution of chromium, cobalt, nickel and zinc in minerals crystallized from magmas are also applicable to rocks composed of such minerals. The quantities of various trace elements in a certain rock are thus functions of its mineral composition.

Researches especially by H. Stille (1940, p. 13 *ff*.) and S. Landergren (1943, 1948 a) necessitate a distinction between rocks of a *primarily magmatic* origin and rocks of a *secondarily magmatic* origin. Stille finds that granitic magmas have been frequently originated by fusion and mobilization of deep-folded sediments (*'palingenesis'*). Landergren asserts that the Swedish iron ores of igneous character cannot possibly be primarily magmatic, *inter alia* owing to their distribution of trace elements.

Other investigators, at first E. Wegmann (1935) and later H. G. Backlund (see especially 1943) have gone as far as to make re-meltings rather unnecessary. They define most granites and gneiss-granites of the crust as *granitized crystalline sediments*. The granitized rocks should have developed by migrations and replacements of ions in the intergranular films of *solid* crystalline sediments. Even magmatic rocks can of course have been granitized similarly.

Much discussion has followed upon this proposal of a new line for the genesis of granites. Various interpretations of the granitization mechanism have been given. *Inter alia*, granitizations by diffusion of undissolved ions have been suggested. As the velocities of diffusion of various ions seem to be very small even under physico-chemical conditions apt for granitizations, we must, however, not accept large-scale migrations of *undissolved* ions through solid crystalline rocks (see I. Th. Rosenqvist 1949, pp. 63—64). On the other hand, mobile, gaseous or liquid, aqueous solutions seem to be highly apt to serve as granitizing agents (*cf*. P. Geijer 1934, p. 634, S. Hjelmqvist 1942, p. 85 *ff*., and Rosenqvist 1949, *l. c.*).

At present, it seems convenient to restrict the use of terms like 'pure magmatic rocks' and 'magmatic differentiates' as much as possible. Wide differentiations especially, implying the division of intermediate magmas into basites and granites, should be regarded with caution (see the following text).

As regards the distribution of chromium, cobalt and nickel in basic magmatic rocks, several data are available. Some of these data are very important, as they display the geochemical consequences of real magmatic differentiations by fractional crystallization.

At first, we shall study the rocks of the Skaergaard intrusion, Greenland (*cf.* p. 7). Wager and Mitchell (1943, pp. 286—87) there obtained the following series (early rocks mentioned first):

| | Mg | $Fe^{+2}$ | $Fe^{+3}$ | Fe | Cr | Co | Ni |
|---|---|---|---|---|---|---|---|
| 1. Gabbro-picrite | 163,400 | 81,800 | 18,800 | 100,600 | 1.000 | 80 | 600 |
| 2. Olivine-gabbro | 58,000 | 81,100 | 10,600 | 91,700 | 200 | 70 | 200 |
| 3. Middle gabbro | 31,700 | 73,800 | 17,600 | 91,400 | $< 1$ | 40 | 25 |
| 4. Hortonolite-ferrogabbro | 33,400 | 129,500 | 26,200 | 155,700 | $< 1$ | 60 | $< 1$ |
| 5. Ferrohortonolite-ferrogabbro | 10,300 | 176,300 | 14,300 | 190,600 | $< 1$ | 30 | $< 1$ |
| 6. Fayalite-ferrogabbro | 1,500 | 207,000 | 28,300 | 235,300 | $< 1$ | 3 | $< 1$ |
| 7. Basic hedenbergite-granophyre | 6,700 | 86,800 | 39,200 | 126,000 | $< 1$ | 20 | 3 |

2—7 represent consecutive layers. Their compositions are in excellent agreement with the differentiation of magnesium, iron, chromium, cobalt and nickel already discovered in single magmatic minerals (Ch. III). The same is, however, only to a certain extent valid for another representative series of basic plutonic rocks, *viz.* that of the Caledonian of Western Scotland. We shall at first quote five analyses from the Garabal Hill—Glen Fyne complex given by Nockolds and Mitchell (1948, p. 538). The differentiation is from oldest to youngest:

| | Mg | $Fe^{+2}$ | $Fe^{+3}$ | Fe | Cr | Co | Ni |
|---|---|---|---|---|---|---|---|
| 1. Dunite | 239,000 | 117,000 | 19,900 | 136,900 | 3,000 | 300 | 1,000 |
| 2. Lherzolite | 143,000 | 73,400 | 10,600 | 84,000 | 2,000 | 200 | 500 |
| 3. Pyroxenite | 117,000 | 81,600 | 30,000 | 111,600 | 3,000 | 100 | 500 |
| 4. Hypersthene-gabbro | 68,200 | 64,200 | 14,200 | 78,400 | 500 | 100 | 300 |
| 5. Main gabbro | 58,900 | 55,400 | 15,100 | 70,500 | 300 | 80 | 200 |

Though still rather early rocks, 4 and 5 show a considerable decrease of chromium, even if the lowered contents of Mg + Fe are reckoned. On the other hand, the three first-differentiates would seem to display quite unexpected trends of the distributions of both chromium and cobalt. In this respect, a comparison between the dunite and the pyroxenite will be of special interest. Although the dunite contains twice as much magnesium and nickel as the pyroxenite, in close agreement with Goldschmidt's rules, the contents of chromium are the same in both rocks. However, we shall now remember that the dunite is mainly composed of olivine (in this case altered into serpentine), whereas the pyroxenite consists of augite and rhombic pyroxene. As I have mentioned earlier (pp. 5—6), the augite structure receives chromium directly, whereas the olivine structure needs a simultaneous supply of lithium. In rocks containing both olivine and clinopyroxene, chromium is also highly concentrated to the pyroxene (*cf.* p. 7: olivine-gabbro, the Skaergaard intrusion). The variation of cobalt mainly seems to be due to the lower value of $\Sigma$(Mg,Fe) in the pyroxenite when compared with the dunite.

On the whole, the plutonic rocks of the Garabal Hill—Glen Fyne complex do not behave as consecutive magmatic differentiates developed by fractional crystallization, however. A late, porphyritic granodiorite belonging to the complex thus contains (Nockolds and Mitchell 1948, p. 539):

$$Cr = 25—30, \ Co = 5—10, \ Ni = 15 \ (n = 2).$$

If only a primarily magmatic differentiation by fractional crystallization should have been at work here, as supposed by Nockolds and Mitchell, we should expect more cobalt, by far less nickel, and no chromium at all.

It ought to be mentioned, that all remaining plutonics of the complex except a residual aplite (see p. 14) contain more chromium than 30. Furthermore, all rocks of the complex except the residual aplite show $Co < Cr \geq Ni$ (19 analyses). 18 analyses show $Co < Cr > Ni$ and as many as 16 analyses $Cr > Ni > Co$, which should be regarded as a genuine first-magmatic order of distribution. Indeed, this anomaly seems to be the result of admixture with the surrounding schists, which are comparatively high in chromium and contain more nickel than cobalt ($Cr > Ni > Co$; for numeric data, see p. 15).

Nockolds and Mitchell also give some data of basic rocks from the Carn Chois intrusion (1948, p. 543). These behave thus:

| | Mg | $Fe^{+2}$ | $Fe^{+3}$ | Fe | Cr | Co | Ni |
|---|---|---|---|---|---|---|---|
| 1. Early olivine-gabbro | 95,400 | 53,500 | 8,100 | 61,600 | 2,500 | 50 | 200 |
| 2. Norite | 53,200 | 73,000 | 13,900 | 86,900 | 400 | 30 | 60 |
| 3. Late pyroxene-mica-diorite (M, n = 2) | 26,500 | 43,850 | 6,750 | 50,600 | 175 | 14 | 45 |

A more rapid decrease of both chromium and nickel would have been expected. Probably, the pyroxene-mica-diorite is no pure magmatic rock but has developed by admixture with schists high in chromium (compare above).

The early intrusive basites of folded mountains are as a rule low in silica and high in magnesium. Further, they are characterized by considerable enrichments in chromium especially, and nickel. These ultra-basites seem to have developed by differentiations by fractional crystallization of unmingled simatic magmas. Their contents of chromium, cobalt and nickel as displayed by the below analyses class them as first-differentiates, according to the rules given by Goldschmidt. They are also chiefly composed of olivine high in magnesium. Moreover, they contain spinels, such as chromite.

High enrichments in chromium separated as chromite are especially common in the peridotites of Ural. Among other peridotites sometimes containing considerable quantities of chromite, I might mention the peridotites of the Swedish Caledonian. T. Du Rietz (1935) gives a number of analyses displaying the character of the latter:

| | Mg | Fe | Cr |
|---|---|---|---|
| Dunite, Junsterklumpen, Jämtland | 297,600 | 52,400 | 2,700 |
| Peridotite, Vuoka Ruopsok, Norrbotten | 275,700 | 61,900 | 4,500 |
| Do., Laisholm, Västerbotten | 271,100 | 72,800 | 3,100 |
| Do.,[1] Säkok Ruopsok, Norrbotten | 264,100 | 64,800 | 4,100 |
| Do., Handöl, Jämtland | 240,300 | 65,500 | 3,500 |
| Do., Stråttekjaure, Västerbotten | 218,200 | 78,800 | 1,500 |
| Do., Muruhatten, Jämtland | 205,400 | 60,400 | 2,300 |
| Do., Kall, do. | 181,100 | 110,300 | 550 |

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[1] Classed as 'saxonite' by Du Rietz.

Further data on simatic first-differentiates will be found in a paper by Th. G. Sahama (1945 a, p. 32). He has analysed a series of Gotho-Karelian (late Archaean, see p. 17) ultra-basites from Southern Finnish Lappland:

| | Cr | Co | Ni |
|---|---|---|---|
| Serpentinite (meta-peridotite) | 13,000 | 250 | ≥ 800 |
| Do. | > 2,000 | 80 | 800 |
| Peridotite | > 2,000 | > 800 | > 800 |
| Talc schist (metabasite) | > 2,000 | 10 | 250 |
| Metabasite mainly composed of amphibole, enstatite and spinel | > 2,000 | 250 | ≥ 800 |
| Metabasite mainly composed of anthophyllite | > 2,000 | 50 | 250 |
| Davainite | 3,600 | 80 | 800 |

We here observe the following order of the three elements considered:

$$\mathrm{Cr} > \mathrm{Ni} > \mathrm{Co}.$$

This order of distribution we have earlier found in gabbro-picrite from the Skaergaard intrusion (p. 10), further in a number of basic rocks from the Caledonian of Western Scotland (pp. 10—11). We have thus seen, that it is characteristic of first-differentiates developed by fractional crystallization of basic magmas.

Now, the compositions of many basites deviate from the rules given for differentiations of basic magmas, as already displayed by the late Garabal Hill—Glen Fyne plutonics (p. 11). And though the compositional trends of the Skaergaard series are both representative of and on the whole due to differentiation by fractional crystallization, there are even here reasons to believe that the variation may to some extent be the result of admixture with the surrounding metamorphic complex (compare the fayalite-ferrogabbro and the basic hedenbergite-granophyre, p. 10; see also Wager and Mitchell 1943, p. 284). Besides, the original Skaergaard magma should have had as much as 600 chromium, according to Wager and Mitchell (1943, pp. 286—87). When we compare this figure with the data given on p. 10, we find that all layered rocks of the Skaergaard intrusion contain less chromium and most of them scarcely any chromium at all. The composition of the Skaergaard magma must thus have changed significantly before its fractional crystallization. In part, this alteration might be due to assimilations of older rocks low in chromium. However, Wager gives another explanation which seems to be by far more convenient. He reckons that a considerable precipitation of $Cr_2O_3$ should have occurred in the early hidden differentiates (Wager and Mitchell 1943, p. 290).

As will be shown later, there also exist many undifferentiated basic rocks which seem to derive from homogeneous secondary magmas probably developed by earlier differentiations of primary basic magmas in the hidden depths. I might here mention an analysis of the Quaternary basalt of Skjaldbreið, an Icelandic shield volcano described by T. Tryggvason (1943; the figures from P. H. Lundegårdh 1946 a, p. 66):

$$\mathrm{Cr} = 23, \ \mathrm{Co} = 550, \ \mathrm{Ni} = 220.$$

In certain cases, we seem to have to go as far as to accept the existence of *wholly* secondary, or palingenic, basic magmas, which should have developed by deep-foldings and re-meltings of basic sediments (compare the introduction of this chapter). Recently, Landergren (1943, 1948 a) investigated the intrusive apatite-bearing iron ores of Central and Northern Sweden from various physico-chemical and statistical points of view. The data obtained forced him to interpret these ores as wholly secondarily magmatic. I shall here quote the most important of his primary data:

| | P | Ti | V | Cr | Co | Ni |
|---|---|---|---|---|---|---|
| Iron ore high in apatite, Grängesberg, Central Sweden (M, n = 32; Landergren 1943, p. 12) | 10,300 | 2,100 | 1,500 | $<$ 10 | 30 | 50 |
| Do., Kiruna, Northern Sweden (M, n = 14; Landergren 1948 a, p. 81) .............. | 11,300 | $\geq$ 2,000 | 1,300 | $<$ 10 | 110 | 160 |

For comparison, I might recall from p. 8 an analysis of iron ore separated from a crystallizing ultra-basic magma (Ti and V added from P. H. Lundegårdh 1946 a, p. 124):

Ti = 70,000, V = 7,000, Cr $<$ 0.5, Co = 50, Ni $<$ 0.5.

As is immediately seen, the ores analysed by Landergren show concentrations of nickel that do not seem to have developed during *normal* differentiation of primary magmas.

Turning to the acid igneous rocks, some of these seem to be secondarily magmatic, whereas other rocks seem to have developed by migrations and replacements of certain dissolved ions in solid sediments (see p. 9). Furthermore, the formation of residual acid melts and solutions is a very common phenomenon in congealing basic magmas. Many occurrences of granite, aplite and granophyre, further many ore deposits, derive from such melts and solutions. The silicate-bearing melts and solutions seem to have been preserved from reactions with the basic mother magma by some kind of squeeze (filter-press action *etc.*).

In the Skaergaard intrusion, Wager found a residual acid granophyre (Wager and Deer 1939, pp. 204—09) that seems to have differentiated from the Skaergaard magma by filter-press action (*op. cit.*, pp. 305—09). This granophyre shows the following composition (the figures are from Wager and Mitchell 1943, p. 287):

Cr = 3, Co = 3, Ni = 5.

The grey gneiss of the metamorphic complex surrounding the Skaergaard intrusion, part of which should have been admixed with the granophyre melt (*op. cit.*, p. 289), runs as follows (*op. cit.*, p. 287):

I. Cr = 3, Co = 15, Ni = 10.
II. Cr = 10, Co = 5, Ni = 8.

The ZrO$_2$ content of the grey gneiss lies between 200 and 250, whereas the granophyre has as much as 400 (*l. c.*). Furthermore, the granophyre contains

110 $ThO_2$ and the grey gneiss only 60—80 (*l. c.*). Although the composition of the grey gneiss may change in the hidden parts of the crust, there are thus reasons to believe that the Skaergaard granophyre really derives from the basic magma.

From the Caledonian of Western Scotland, Nockolds has described residual ('end-stage') aplites which cut the granodiorite of the Garabal Hill—Glen Fyne complex (1941). These aplites were analysed by Mitchell (Nockolds and Mitchell 1948, p. 539):

I. Cr = 1, Co $<$ 2, Ni = 3.
II. Cr $<$ 1, Co $<$ 2, Ni $<$ 2.

An analysis of residual aplite from the Glen Etive complex is also given (*op. cit.*, p. 543):

Cr $<$ 2, Co $<$ 2, Ni = 3.

A number of granites will be considered next. The samples analysed derive from rocks many of which seem to have little or no relation to primary magmas.

13 Archaean granites from Finland analysed by Sahama (1945 a, pp. 27—28) and K. Rankama (1946, pp. 37—38) contain:

Cr = 0—20, M = 4.
Co = 0— 8, M $\leq$ 3.
Ni = 0— 2, M = 1.5.

A standard mixture of Finnish Rapakivi granites has been analysed by Sahama (1945 b, p. 44):

Cr = 30, Co = 0, Ni = 2.

An average granite material prepared by W. Noll from 14 German granites has been analysed by Mitchell (Wager and Mitchell 1943, p. 287):

Cr = 2, Co = 8, Ni = 2.

Recently, Landergren (1948 a, p. 59) gave a geochemical survey of the early Archaean leptites of the iron ore region of Central Sweden — a series of acid, very fine-grained, high-metamorphic, supra-crustal rocks which most probably includes both volcanics and sediments (see p. 23). Of 32 samples, 31 show the following composition:

Cr = 10—300, M = 50.
Co $<$ 10— 30, M $<$ 30.
Ni $<$ 10—100, M = 20.

The 32nd sample, a red leptite from the Säter mines, gave 2,000 chromium, an extreme enrichment, indeed, especially when discovered in an acid rock.

The compositions of early Archaean leptites and Rapakivi granites given by Landergren and Sahama should be compared with the analyses of various sediments given below. Landergren and Sahama obtained the following average order of distribution of the three trace elements considered: Cr $>$ Ni $>$ Co. This order does not seem to occur in acid residuals developed by squeeze of crystallizing basic magmas, as exemplified by the Skaergaard granophyre and the Scottish Caledonian aplites (see above). On the other hand, it has been found in a great many sediments. Thus, for instance, the Rapakivi granites may very well have developed by granitization of sediments similar to the Lapponian quartzites (p. 16).

As regards trace elements in siliceous inorganic sediments, we possess a number of modern data given by Landergren, Mitchell and Sahama. The former recently analysed three cores of sediments from the Tyrrhenian Sea in Western Mediterranean (Landergren 1948 b):

| Core | Fe | Cr | Co | Ni |
|---|---|---|---|---|
| No. 13 | 59,500 | 30 | 28 | 39 |
| No. 15 | 58,300 | 80 | 27 | 40 |
| No. 16 | 63,000 | 50 | 24 | 38 |
| General average | 60,500 | 38 | 27 | 39 |

Of 12 samples from various levels of core no. 13, which were analysed for chromium, cobalt and nickel, four show the following distributions (oldest sediments mentioned first):

| | Cr | Co | Ni |
|---|---|---|---|
| I | 20 | 25 | 40 |
| II | 10 | 30 | 30 |
| III | 20 | 20 | 60 |
| IV | 20 | 25 | 50 |

In six of the eight remaining samples, Cr is higher than Co, or both Co and Ni. In two samples, Co is higher than Cr and Ni. In 42 samples of all 56 analysed, Ni is higher than Co. In six, Ni is equal to Co.

In metamorphic sediments (schists) from the interior (remnants) and the surroundings of the Caledonian Garabal Hill—Glen Fyne complex, Western Scotland, Mitchell found the following concentrations of chromium, cobalt and nickel (Nockolds and Mitchell 1948, p. 545):

| Character | Cr | Co | Ni |
|---|---|---|---|
| Hypersthene-biotite-plagioclase hornfels, with cordierite and spinel, *remnant* | 600 | 30 | 70 |
| Hornblende-diopside-plagioclase-quartz hornfels, *contact* | 300 | 20 | 50 |
| Biotite-plagioclase-corundum hornfels, *near contact* | 250 | 15 | 25 |
| Do., do. | 200 | 12 | 25 |
| Biotite-andalusite-cordierite-plagioclase hornfels, *near contact* | 150 | 10 | 25 |
| Biotite-cordierite-albite-quartz hornfels with band containing andalusite and sillimanite, *near contact* | 150 | 10 | 25 |
| Garnetiferous mica-albite schist | 200 | 12 | 30 |
| Siliceous garnetiferous mica schist | 70 | 3 | 10 |
| Garnet-mica schist | 50 | 10 | 30 |
| Mica-albite-quartz schist | 40 | 12 | 18 |
| Biotite-muscovite-albite-quartz hornfels with some potash feldspar | 30 | 8 | 15 |

We immediately observe an enrichment in chromium towards the contacts of the basic plutonic rocks. We further observe that Ni is always higher than Co.

A number of Gotho-Karelian sedimentary rocks from Southern Finnish Lappland have been analysed by Sahama (1945 a, pp. 38—39):

| Character | Cr | Co | Ni |
|---|---|---|---|
| Quartzites belonging to the Kumpu-Oraniemi series | 200 | 0 | 10 |
| Lapponian quartzites | 70 | 0 | 2—3 |
| Leptitic schists (high-metamorphic clay slates), belonging to the Kumpu-Oraniemi series | 2,100 | 10 | 10 |
| Do., Lapponian | 300 | 10 | 25 |
| Schists high in alumina, belonging to the Kumpu-Oraniemi series | 300 | 10 | 25 |
| Do., Lapponian | 350 | 10 | 25 |

These are all sediments that seem to derive from rocks abnormally high in chromium.

A similar concentration of chromium characterizes the Old Red sandstone of North-eastern Scotland, as evident from three analyses of typical soils from this region (Mitchell 1946, p. 362):

| Soil derived from | Cr | Co | Ni |
|---|---|---|---|
| Granite | 5 | < 2 | 10 |
| Norite | 50 | 30 | 15 |
| Old Red sandstone | 200 | 18 | 60 |

Among older analyses of sediments, we shall here consider those by G. Steiger in Clarke's *'Data of Geochemistry'* (Clarke 1924, pp. 509 and 518):

<table>
<tr><th>Character</th><th>Cr</th><th>Co</th><th>Ni</th><th>Zn</th></tr>
<tr><td>Red clays from the deepest abysses of the oceans, composite of 51 samples</td><td>80</td><td colspan="2">305</td><td>40</td></tr>
<tr><td>Marine terrigenous clays deposited near land, composite of 52 samples</td><td>330</td><td colspan="2">490</td><td>55</td></tr>
<tr><td>Delta silts from Mississippi, composite of 235 samples</td><td>70</td><td>—</td><td>130</td><td>8</td></tr>
</table>

As regards zinc in rocks and soils, I might refer to an earlier paper (P. H. Lundegårdh 1947 b). The analyses of Swedish rocks and soils there given are included in the tables of my present paper. The number of older, significant determinations is restricted. An average analysis of 329 American crystalline rocks given by Clarke (1924, p. 642) and amounting to Zn = 50 should, however, be mentioned. Some further evidence will be found in the above analyses by Steiger. The low content of zinc in the Mississippi delta silts is remarkable, especially as these, though rather acid ($SiO_2$ = 699,600), are not so very low in Fe (24,300) and Mg (8,500; all three figures from Clarke 1924, p. 509).

In 1943, E. B. Sandell and S. S. Goldich published a number of new analyses of American igneous rocks. An average for zinc of 130 was found for 25 basic rocks and of 63 for 29 acidic ones (1943, p. 172). Numerous data for cobalt and nickel are also given in Sandell's and Goldich's paper.

### B. Division of Analysed Rocks and Soils.

253 representative samples of Swedish rocks and soils, 169 of which are general samples, have been analysed by the writer. These compose Tables 1—15. The division used corresponds to the following scheme:

### I. Svionian (early Archaean).

1. Acid volcanics and sediments, high-metamorphic (leptites, leptite gneisses, gneisses; Table 1, see also Landergren 1948 a, p. 59). Iron ores (investigated by Landergren, 1943 and 1948 a). Basic volcanics, high-metamorphic (Table 5. These rocks are associated with the upper, femic leptites at the end of Table 1).
2. Clay and silt slates (Grythytte series, Larsbo series[1]) including high-metamorphic derivatives such as leptites, veined gneisses and mica schists (Tables 11—14). Basic volcanics, high-metamorphic (Table 5).[1]
3. Svecofennian basites and granites (igneous rocks developed during the Svecofennian folding of 1—2 above; Tables 2 and 6).
4. Massive, plutonic ultra-basites (Table 7, see also P. H. Lundegårdh 1947 a). Vätö granite (associated with the massive ultra-basites; Table 3, see also P. H. Lundegårdh 1946 a, pp. 136—38).
5. Basic dikes (Table 9).
6. Massive, plutonic basites (Table 8). Femic granites (associated with the massive basites; Table 8).
7. Hedesunda granite and associated syenite (Table 3).
   Malingsbo granite (Table 3). Stockholm granite (Table 3).

### II. Gotho-Karelian (late Archaean), very approximate division.[2]

1. Volcanics and sediments, high-metamorphic (gneisses, palingenic granites, metabasites; Tables 1 and 9).
2. Massive, plutonic basites (Table 8: Gotho-Karelian, first section of four rocks).
3. Acid volcanics and slates (Tables 4 and 15).
4. Massive, plutonic basites and ultra-basites (Table 8: Gotho-Karelian: second section of seven rocks; Table 7).
5. Växjö granite (Table 3). Filipstad granite (Table 3).
6. Massive?, plutonic basite (Table 8: Gotho-Karelian, third section of one rock). Basic dikes (Table 9: amphibolite, uralite-diabase, hyperite).
7. Clay slates (Dal series, Kalix series? Tables 11, 12 and 13) including high-metamorphic derivatives.
8. Bohus granite (Table 3).

### III. Algonkian.

1. Sub-Jotnian rocks (porphyries, hypabyssal syenitic granite, diabase; Tables 4 and 9).
2. Jotnian rocks (diabase, granophyre; Tables 9 and 4).

### IV. Palaeozoikum.

1. Cambrian sediments (Tables 11, 13 and 15).
2. Ordovician sediments (Tables 11, 13 and 15).
3. Plateau-diabase (Table 9).

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[1] Classed as uppermost early Svionian, or 'Bottnian'.

[2] Compare W. Larsson 1947.

### V. Mesozoikum.

1. Triassic clay, leached (Table 14).
2. Cretaceous clay, leached (Table 14).

### VI. Tertiary.

1. Eocene clay (Table 11).
2. Volcanics (basalt, rhyolite; Tables 9 and 4).

### VII. Quaternary.

1. Glacial clays and silts (Tables 10 and 11).
2. Post-Glacial sediments (Tables 11, 13 and 15).

As regards the above scheme, I might give a few explanations. The term *Svionian* was originally proposed by J. J. Sederholm. In 1936 (a), N. H. Magnusson redefined it and gave it its present meaning: the evolution of the early Archaean rocks. In accordance with Magnusson's definition, the Svionian era includes the *Svecofennian* folding (W. Ramsay—W. Wahl, see Wahl 1936), which deformed the early Svionian rocks.

*Bottnian* (foot-note 1, p. 17) is also a Finnish term, employed by Sederholm and E. Mäkinen for certain early Archaean sediments, which should form equivalents to the Larsbo series of Central Sweden (S. Hjelmqvist 1938, pp. 37—38). Recently, Magnusson (personal communication) has proposed a new, neutral term for the Swedish Larsbo sediments, *viz.* the *Mälar series*.

*Gotho-Karelian* is composed of the *Gothian* and *Karelian* eras as defined by Magnusson (1936 a). This term was originally suggested by Backlund (1937), who also included Algonkian in Gotho-Karelian, however.

The post-Gotho-Karelian eras will be familiar to the reader.

## C. Discussion of Results.

The primary data which will be discussed here are all included in Tables 1—15. The distributions of chromium, cobalt, nickel and zinc are summarized in Tables 16—19. A review of the geochemical trends discovered are given in Table 20.

With rather few exceptions (compare p. 11), the Swedish bed-rock is very low in chromium, as especially evident from the analyses of various sediments derived from there (Table 16). Of 73 sedimentary rocks[1] and soils of various ages and constitutions, 54 contain $< 10$ and 68 $< 25$ chromium. The maximum concentration amounts to 30 (3 samples).

Among the igneous rocks analysed by the writer, the Svecofennian basites (Table 6) are on the whole highest in chromium. 8 samples of 24 contain $\geq 300$ and 5 samples $\geq 600$ of this metal. The mother magma of the Svecofennian basites intruded into the early Svionian rocks (leptites *etc.*) during the Svecofennian folding and differentiated in accordance with Goldschmidt's rules.

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[1] Excl. the leptites and gneisses of Table 1.

Thus, the earliest members of the series, such as the lherzolites, show considerable enrichments in chromium and are characterized by the following order of distribution: Cr > Ni > Co. Furthermore, the latest differentiates frequently lack chromium. As would also be expected, nickel decreases more slowly though to some extent irregularly, whereas cobalt is uniformly distributed to various members of the series. The contents of the volatile zinc are highly variable. The abnormal distributions of chromium, cobalt and nickel now and then encountered are most probably due to inevitable admixture with the early Svionian rocks penetrated by the rising magma. Contaminations seem to be especially frequent in the late differentiates (see below; compare also Landergren 1948 a, pp. 154—156).

The Svecofennian basites were earlier interpreted as differentiates of the mother magmas of the Svecofennian granites (p. 24 *ff.*). However, the trace element analyses given in Tables 2 and 6 bear evidence against such a relationship. Thus, for instance, the gabbro at Uppsala contains by far less chromium (Cr = 5) than the surrounding Uppsala granite (Cr = 25). If these rocks had crystallized from a common magma, the reverse order of distribution should have been obtained. Furthermore, such an ultra-basic rock as the lherzolite W of Klockarbo, Kopparbergs län (Cr = 650, Co = 35, Ni = 400), occurs within a grey gneiss-granite showing the same distribution of the trace elements analysed (Cr = 2, Co = 15, Ni = 4) that characterizes normal late-magmatic *basites* (compare the rocks of Table 5). Indeed, we cannot possibly go farther than admitting that the gneiss-granite at Klockarbo might have been admixed with late-magmatic femic silicates separated as a residual melt from the crystallizing lherzolite. Besides, there exist no transitional Svecofennian basites around or even in the close vicinity of the Klockarbo lherzolite.

As will be seen later, heat and volatiles liberated from the crystallizing Svecofennian basic magma seem to have contributed largely to the metamorphism of the leptites. Most occurrences of Svecofennian basites are also found within Svecofennian granites, *viz.* wholly fused leptites. As would be expected, the early, ultra-basic differentiates (lherzolites *etc.*) have as a rule remained intact, whereas the late, dioritic differentiates most frequently show complete gradations into the surrounding granites. Indeed, the late Svecofennian basites do not seem to have congealed completely till the surrounding leptites fused and became highly reactive.

The Gotho-Karelian era also includes differentiated basites (Table 8), part of which have most probably intruded during foldings (Larsson 1947). Among the latter we have to count the uralite-porphyrite and the uralite-gabbro near Onsala, Hallands län.[1] The uralite-porphyrite is ultra-basic and of an early formation, whereas the uralite-gabbro should be classed as a middle differentiate. Their contents of chromium, cobalt and nickel are in harmony with the order of differentiation thus given.

The norites of Östergötlands län have been in part investigated by B. Asklund (1923, 1925), who could there distinguish various differentiates of great petro-

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[1] According to recent, unpublished investigations by the writer.

logical interest (Asklund 1925). The differentiation discovered by Asklund is beautifully reflected by two analyses of the norite at Normstorp and four analyses of a related[1] norite near Ingarp, Jönköpings län (Table 8). The geochemical trends displayed by these analyses are in concord with Goldschmidt's rules. It is, however, peculiar, that no peridotitic differentiates occur in the series. Indeed, a basite from the SE part of Östergötlands län contains as much as 250—300 chromium (Asklund 1923, p. 23), though having yet developed as norite.

We shall now turn to the post-Svecofennian, Svionian ultra-basic gabbro of Roslagen, Stockholms län (see P. H. Lundegårdh 1941, 1943, 1946 a and 1947 a), which is characterized by an abnormal distribution of chromium. This gabbro (An = 85—95 % of the plagioclase) would be expected to show considerable enrichments in chromium. All early intrusions, such as the Grovstanäs massif, are, however, remarkably low in chromium ($Cr \leq 6$), even the peridotitic first-differentiates (Table 7). On the other hand, the late intrusions, which show similar bulk compositions (P. H. Lundegårdh 1947 a, p. 36), are by far higher in the metal mentioned ($Cr = 55—220$).

In order to interpret the differentiation thus encountered, I analysed two general samples from an occurrence of similar though Gotho-Karelian gabbro, *viz.* the Eriksberg massif in Värmlands län (see Magnusson 1925, pp. 101—04). Here, the early allivalite is equally low in chromium ($Cr = 3$) as the early ultra-basic gabbro of Roslagen, whereas the late olivine-gabbro contains 100 chromium (Table 7).

I found once again this peculiar trend when investigating a late Svionian gabbro, which has intruded in close connection with the development of the palingenic porphyritic granites of Uppsala, Gävleborgs and Kopparbergs län (Table 8). Here, an early uralite-gabbro has given $Cr = 1$, whereas two general samples of an apparently undifferentiated, in part gabbroic diorite show $Cr = 150—200$. One of the latter has the first-magmatic order of distribution, $Cr > Ni > Co$.

Among various possible explanations of the trend thus exemplified, I might mention the development of an early crystallized phase high in chromium and the separation by squeeze of a residual basic magma very low in this metal (compare p. 12: basalt, Skjaldbreið, Iceland). The residual magma should have been rich in volatiles and thus apt to intrude more rapidly into higher parts of the crust than the remaining original magma, further to differentiate there into various rocks even within small masses, such as the Grovstanäs massif. This hypothesis is applicable to the early ultra-basic gabbro of Roslagen, as exemplified by the heterogeneous, banded Grovstanäs gabbro (Table 7; see also P. H. Lundegårdh 1943 and 1947 a). The late, by far less differentiated ultra-basic gabbro of Roslagen should then represent the original gabbro magma.

On the other hand, the gabbro at Eriksberg certainly has another origin. The early allivalite there grades into the late olivine-eucrite. The lack of chro-

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[1] According to recent, unpublished investigations by the writer.

mium characterizing the former merely seems to be due to the complete absence of minerals apt to receive chromium in their structures, such as spinel, primary ore and augite. Indeed, a microscopical investigation of the two samples analysed gave the following information:

| *Allivalite.* | *Olivine-eucrite.* |
|---|---|
| Superior minerals: *Bytownite-anorthite* (An = 90 %) > *Forsteritic olivine* ($Fe_2SiO_4$ = 7 %) highly altered into *serpentine* with *magnetite*. | Superior minerals: *Basic bytownite* (An = 85—90 %) > $\Sigma$ (*Augitic diallage* > *Pigeonite* > *Bronzite*) $\geq$ *Uralite* $\geq$ *Olivine* ($Fe_2SiO_4$ = 15 %) in part altered into *serpentine* with *magnetite*. |
| Inferior minerals: *Uralite* ≈ *Chlorite* (secondary) > *Enstatite* > *Prehnite* (secondary). | Inferior minerals: *Primary ore* > *Muscovite* (secondary) > *Apatite* (rare). |

The late Svionian gabbros and diorites of Uppsala, Gävleborgs and Kopparbergs län are most frequently uralitized and thus not very apt to considerations regarding their differentiation. There are, however, even here indications of the initial formation of a separate, highly mobile basic melt showing abnormal composition, especially as the early palingenic gneiss-granite associated with the basites is as low in chromium and high in nickel as the early gabbro (Table 8). It seems, indeed, very probable that the early secondary granite melt developed simultaneously with the intrusion of the early, abnormal basic magma and that the granite melt became admixed with part of this basic magma. The early palingenic gneiss-granite is also on the whole remarkably femic.

Basic rocks low in chromium are on the whole very common in the Swedish bed-rock, though most of them do not display such abnormal characters as the above ones. We shall here at first study the layered early Svionian basic volcanics of Central Sweden (Table 5[1]). These are concentrated to the upper parts of the leptite series of acid volcanics and sediments. Accordingly, they are widely distributed as remnants in various palingenic derivatives of the leptites, especially the Svecofennian granites, the compositions of which they have also largely influenced (see p. 25).

The early Svionian basic volcanics are high-metamorphic — metabasitic, and in general developed as amphibolites or uralite-porphyrites. The samples analysed show a striking deficiency of chromium, whereas the cobalt content is normal. Nickel as a rule occurs in appreciable quantities, but is less important than cobalt. We thus obtain the following order of distribution (Table 20):

$$\mathrm{Co} > \mathrm{Ni} > \mathrm{Cr},$$

which should be regarded as typical of late-magmatic rocks, according to Goldschmidt's rules.

The early Svionian metabasites are frequently associated with basic leptites —

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[1] Excl. one sample of 'Bottnian' metabasite, which will be discussed later (p. 22).

meta-dacites and similar rocks, which seem to show the same distribution of the three trace elements considered (Table 1: leptite gneiss, femic, dark grey, Gävleborgs län).

During the Svecofennian folding, the lower parts of the leptite series were fused and most frequently mobilized. The layers of metabasites included in the fused leptites were disintegrated and admixed with the leptites. When the latter congealed so as to develop Svecofennian granites (p. 24), the non-assimilated remnants of basites were preserved as dark, amphibolitic spots. A number of analyses of such remnants are given in Table 5. They show the same distribution of chromium, cobalt and nickel as the massive layers investigated, although the surrounding granites are most frequently higher in chromium, sometimes in nickel, too (Table 2, I). No diffusion of these metals thus seems to have occurred.

On turning to similar pre-Svecofennian basites of later formation, we observe that the rock at the end of Table 5 contains as much as 70 nickel, further 15 chromium and 10 cobalt. This metabasite occurs as layers in the Southern Upplandian veined gneisses, which should be classed as high-metamorphic equivalents to the 'Bottnian' Larsbo series of southernmost Kopparbergs län (Hjelmqvist 1938, pp. 36—37).[1] The latter is composed of sediments (in part silts) deposited on the leptites and early Svionian metabasites above described.

On the other hand, we have in Eastern Sweden a series of post-Svecofennian, Svionian meta-basites (Table 9), which form geochemical equivalents to the metabasites of the leptite series. From a genetical point of view, these rocks are very important, as they are intimately associated with and sometimes grade into meta-andesites and meta-dacites still high in cobalt but also containing considerable quantities of chromium and nickel (Table 9). Although the latter are rather acid, they have developed earlier than the metabasites (Magnusson 1940, pp. 77—78; P. H. Lundegårdh 1946 a, p. 89 *ff*.). This reverse order of differentiation should be born in mind when comparing the early Svionian metabasites with the leptites as a whole. As is shown by Landergren's analyses of various leptites from the iron ore region of Central Sweden (p. 14), these contain on average $Cr = 50$, $Co < 30$, $Ni = 20$, and may thus suggest a geochemical differentiation similar to the above one. We cannot yet judge of the nature of this supposed differentiation, however, owing to the high-metamorphic and composite character of the leptite series. Besides, many leptites are by far lower in chromium than the samples investigated by Landergren (see Table 1).

On continuing our study of Table 9, we find a metabasite which probably belongs to the early Gotho-Karelian, although it shows the same composition as its Svionian relatives. This metabasite occurs as big remnants in a marginal Gotho-Karelian uralite-gabbro (parish of Västerlösa, Östergötlands län; see Table 8). The remaining Gotho-Karelian basic dike rocks and volcanics analysed are all low in chromium, whereas cobalt and nickel show normal concen-

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[1] The areal distribution of the 'Bottnian' metabasite thus discovered seems to be quite insignificant as compared with that of the older metabasites above described. In the following text, the term 'early Svionian metabasites' will also be exclusively applied to the latter.

trations. The same can be said of most Algonkian diabase samples, though a trend indicating a normal magmatic differentiation here appears. The areal distribution of the early varieties high in chromium is, however, insignificant. Perhaps the mother magma of these has not been able to rise as high in the crust as that of the late varieties, which was, indeed, very rich in volatiles (compare the amygdaloids of the Gävle diabase) and thus certainly very mobile.

Close to the end of Table 9, we find two samples of Palaeozoic plateau-diabase which are both equally low in chromium as most of the aforementioned rocks. The Västgöta diabase resembles the Quaternary plateau-basalt of Skjaldbreið, Iceland (p. 12), very much:

| | Cr | Co | Ni | Zn |
|---|---|---|---|---|
| Västgöta diabase | 6 | 400 | 200 | 230 |
| Basalt, Skjaldbreið | 23 | 550 | 220 | 250 |

None of these rocks have developed by visible magmatic differentiation. We shall now compare the Skjaldbreið basalt with a typical early Svionian metabasite from Table 5:

| | Cr : Co : Ni : Zn |
|---|---|
| Amphibolite, parish of Älvkarleby, Uppsala län | 3 : 50 : 20 : 65 |
| Basalt, Skjaldbreið | 2 : 50 : 20 : 23 |

Geologically, the early Svionian metabasites are as wide-spread and homogeneous as the plateau-diabase and plateau-basalt just studied. All three groups of rocks should be classed as late middle or late magmatic differentiates of basic magmas. They are, however, not associated with any visible early or early middle magmatic differentiates. Indeed, their mother magmas seem to have been removed from an earlier crystallized phase by squeeze. This phase should have been high in chromium especially, and nickel (compare p. 12: the initial differentiation of the primary Skaergaard magma as interpreted by Wager).

Even the Tertiary basalt at the end of Table 9 is low in chromium. However, this rock forms distal apophyses of the basic magmas rising during Tertiary and can thus be suspected to have become highly admixed with foreign rocks before its solidification.

Of the various Swedish rocks and soils analysed by the writer, the acid igneous rocks are on the whole lowest in chromium. Indeed, all 80 samples (incl. the leptites and gneisses of Table 1) show Cr $< 30$. 72 samples have given figures $< 10$ (*cf.* Table 16).

The oldest Swedish silicate rocks — the fine-grained early Svionian leptites, form layers and beds. During the Svecofennian orogenesis, they were penetrated by rising basic magma (p. 18), folded, re-heated and re-crystallized. Part of them grew coarser and changed into gneisses, part of them fused and gave origin to secondary magmas. At present, we can thus say little of the original character of most leptites. There are, however, indications that some leptites have developed as volcanics and other as sediments of eroded matter. There even exist leptites which still show primary volcanic structures, for instance in the Grythytte field, Örebro län (N. Sundius 1923). Further, we have leptites the geological positions and petrological characters of which reveal their origin. Thus, one volcanic group of leptites is distinguished by its association with the early Svionian metabasites (p. 21) and another, sedimentary group by its association with the clay and silt derivatives in Södermanlands and Stockholms län (the leptites of Table 12).

A number of analyses of leptitic rocks from easternmost Central Sweden is given in Table 1. The variable origin of the rocks analysed is reflected by the varying contents of the four trace elements determined. Further evidence on the variable composition of leptites will be found in Landergren 1948 a, p. 59.

The acid magmas that ejaculated the volcanic leptites should have congealed during the Svecofennian folding. Most Swedish petrologists agree, that the resultant rocks are included in the Svecofennian series of granites. Many investigators claim, that each of these rocks should show the same chemical composition as the corresponding volcanics. Certain petrologists have gone as far as to interpret *all* Svionian silicate rocks except the uppermost early Svionian schists as the supra-crustal and *all* Svecofennian rocks as the infra-crustal products of a continued magmatic activity.

Such a conception can of course be valid *only* if we are allowed to interpret the leptites as the original silicate crust of the earth. However, investigations by Backlund (1941, 1943) have shown the existence of two geological cycles which are older than Svionian, *viz.* Mare-Albian and Norvego-Samian. Furthermore, the discovery of an extensive series of high-metamorphic early Svionian sediments correlated to the Finnish Bottnian sediments, *viz.* the Larsbo series (described by Hjelmqvist in 1938), proves the existence of an early Svionian geosyncline which was most probably folded in like manner as later geosynclines (Wegmann 1929, Backlund 1936). Now, Stille has shown that the development of palingenic granites is typical of folded geosynclines (compare p. 9). And, as early as in 1937, Hjelmqvist interpreted *all* Svecofennian granites in the surroundings of Smedjebacken, Kopparbergs län, as palingenic rocks (Hjelmqvist 1937, p. 42). Later, Hjelmqvist has continued his petrological investigations in Central Sweden along the line thus given.

In view of the actualistic aspects to the bed-rock of Central Sweden as advanced by Hjelmqvist, it seems dangerous to regard chemical similarities between neighbouring leptites and Svecofennian granites as indications in favour of a mutual magmatic origin of both. Besides, the mother magmas of the early Svionian volcanics would be expected to have moved considerably during the Svecofennian folding and to have got their compositions highly changed by admixture with foreign matter — rising basic magma (p. 18), fused leptites and metabasites, before their eventual solidification as granites.[1]

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[1] In the following text, these rocks are included in the palingenic series of granites, as they do not seem to show any special characteristics.

During the Svecofennian folding, the fused, mobilized leptites intruded into solid folds of leptites and early Svionian metabasites. These palingenic leptite magmas were most probably admixed with volatiles received from the mother magmas of the Svecofennian basites (compare p. 26: Jotnian granophyre, the Breven dolerite dike). They thus became highly fluid. The enrichment of the resultant Svecofennian granites in zinc (Table 2, I) and the high frequency of sulphide ores around these granites speak in favour of such an admixture. Further evidence will be found in the metasomatic alterations of various early Svionian rocks and ores[1] as effected by the Svecofennian granite magmas and in the concordant, sheet-like distribution of most Svecofennian granites. Magnusson, who has studied in detail the mode of intrusion of the Svecofennian granite magmas, also characterizes these as highly penetrative and mobile solutions, *viz.* silicates dissolved in volatile compounds (abstract from various papers by Magnusson).

As regards original constituents, the compositions of the palingenic Svecofennian granites should as a rule reflect the compositions of the parental leptites, which were certainly highly variable (Table 1 and Landergren 1948 a, p. 59). Indeed, the Svecofennian granites analysed in Table 2, I, show highly variable contents of chromium, cobalt and nickel, whereas the volatile zinc secondarily received is more uniformly distributed.

Voluminous leptite melts could of course effect a certain homogeneization and should also have been able to dilute the volatiles secondarily added, with the result of an increased viscosity. Furthermore, these melts have most probably been admixed with the mother magmas of the volcanic leptites, which had certainly evaporated most of their volatiles during early Svionian. Thus, extensive masses of Svecofennian granites, such as the Uppsala granite, are both discordant and rather uniform as regards the rocks composing them. Geijer, who has investigated various large intrusions of Svecofennian granites, classes these as anticlinal batholiths (Geijer 1916).

The metabasite layers of the early Svionian strata were less apt to fuse than the surrounding leptites and were thus frequently transported as solids by the secondary magmas. Part of these solids are still preserved as dark inclusions of amphibolite (Table 5) in many Svecofennian granites. As can be expected, granites derived from leptites rich in layers of metabasites are both more femic and higher in dark inclusions than the ordinary Svecofennian granites. The chemical compositions of such granites have also been highly influenced by the metabasites. This is beautifully exemplified by the Uppsala granite (compare above), the voluminous mother magma of which was apparently able to assimilate considerable quantities of disintegrated basites. Indeed, a general sample of the Uppsala granite (Table 2, I) shows:

$$\mathrm{Cr} = 25,\ \mathrm{Co} = 45,\ \mathrm{Ni} = 20.$$

For comparison, we shall reconsider the leptites of the iron ore region of Central Sweden as analysed by Landergren (see p. 14):

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[1] See, for instance, P. Eskola 1914 and Geijer 1917.

$$Cr = 50, Co < 30, Ni = 20.$$

We shall also give the average composition of the early Svionian metabasites:

$$Cr = 2, Co = 40, Ni = 10.$$

On the whole, the palingenic Svecofennian granites analysed (in Table 2 distinguished as 'main fraction') rather well reflect assimilations of disintegrated metabasites (and, of course, fusions of associated basic leptites). In Table 20, we find that most of these granites (14 samples of 25) correspond to the following, 'metabasitic' order of distribution:

$$Cr < Co \geq Ni; \; Co \geq 3; \; Zn \geq 30.$$

As would be expected, the granites mentioned are frequently rich in remnants of amphibolite.

On the other hand, the *late* Svecofennian granites of Table 2 as a rule lack basic remnants. On the whole, these rocks also differ considerably from the palingenic granites above described, both in their mode of intrusion (Even small masses are frequently discordant) and regarding their bulk composition (They are always acid and high in microcline).

The late Svecofennian granites may have in part developed by fusion and re-crystallization of salic leptites free or almost free from layers of metabasite. However, as the known layers of such leptites are concentrated to the lowest parts of the early Svionian strata, the salic palingenic melts should have developed early and should have been fluid all during the Svecofennian folding. It seems highly improbable that they have not then become admixed with foreign matter. Further, it seems peculiar that they should have avoided existing strata of metabasites during their way upwards. We may therefore reckon that the late Svecofennian granites have quite another origin. Indeed, there are strong indications that their magmas have developed by filter-press actions during the crystallizations of the Svecofennian basites and granites above described.

We have already studied a number of rocks which have developed similarly, *viz.* the Skaergaard granophyre and the Scottish Caledonian aplites (pp. 13—14). I shall here also remember of the Vätö granite in Roslagen (Table 3), which I a few years ago interpreted as a late acid differentiate of the parental magma of the ultra-basic gabbro there occurrent (P. H. Lundegårdh 1946 a, pp. 136—37, 1947 a, p. 44). Finally, I shall call attention to the acid granophyre of the Jotnian Breven dolerite dike, parishes of Bo and Regna, Örebro and Östergötlands län (Table 4). T. Krokström (1932) has shown that the intruding granophyre melt was highly enriched in volatiles evaporated from the magma of the dolorites. The concentration of zinc in the sample analysed is also as high as 150. For comparison it might be mentioned that the dolerite contains 55 zinc (Table 9).

I shall give here the distributions of chromium, cobalt, nickel and zinc in the acid rocks now mentioned (for details, see pp. 13—14 and Tables 2: II, 3 and 4):

| | Cr | Co | Ni | Zn |
|---|---|---|---|---|
| Late Svecofennian granite, Bergshamra | 2 | ⩽ 1 | 1 | 10 |
| Do., Penningby | 2 | ≤ 1 | 2 | 30 |
| Do. (developed as gneiss), Villinge | ⩽ 1 | ⩽ 1 | ⩽ 1 | 40 |
| Late Svecofennian granite, Vänge | 1 | < 1 | < 1 | 80 |
| Do., Gottröra | < 1 | < 2 | < 1 | 40 |
| Do., Österskär | < 1 | < 1 | < 1 | 190 |
| Vätö granite, Roslagen | 1 | ≤ 1 | ≤ 1 | < 5 |
| Do., do. | 1 | < 1 | 1 | < 5 |
| Do., do. | 1 | < 1 | 2 | < 5 |
| Do., do. | 1 | < 1 | 1 | < 15 |
| Granophyre, Breven | 1 | < 1 | < 1 | 150 |
| Aplite, Western Scotland | 1 | < 2 | 3 | — |
| Do., do. | < 1 | < 2 | < 2 | — |
| Do., do. | < 2 | < 2 | 3 | — |
| Granophyre, Skaergaard | 3 | 3 | 5 | — |

According to Sundius (1948, p. 32), the late Svecofennian granite of Österskär (developed as porphyritic quartz-syenite) should be classed as a final product of the magmatic activity during Svecofennian. Consequently, its content of zinc is very high.

The microcline eyes characterizing certain intermediate, gneissic, palingenic Svecofennian granites, such as the Vaxholm granite (Table 2, II), should have crystallized from penetrative solutions separated from the magmas of the late granites. As pointed out by Sundius (1939, pp. 26—27), the porphyritic gneiss-granite is intimately related to the common gneiss-granite, actually showing a complete series of gradations into this rock. The eyes cannot thus possibly be primary.

The interpretation now given is also in harmony with the peculiar lack of zinc in certain porphyritic varieties (Table 2, II). When sufficiently acid, the penetrative solutions have apparently removed all zinc originally contained in these rocks and re-deposited it somewhere else.

The various post-Svecofennian granites, porphyries *etc.* analysed by the writer (Tables 3—4) are all extremely low in chromium, cobalt and nickel, whereas considerable enrichments in zinc are frequently met with (*cf.* P. H. Lundegårdh 1947 b). According to modern interpretations (compare p. 9), most of these rocks[1] should derive from sediments high in feldspar and quartz (compare Table 15). As they behave as magmatic rocks, *viz.* form intrusions in and effusions on the crust, they have, however, to be regarded as fused, mobilized sediments, not as products of granitizations in the solid silicate phase.

In a few cases, certain kinds of admixed matter can be traced in the acid rocks thus developed by palingenesis. The Hedesunda granite N of Gillerås, Gävleborgs län (Table 3), for instance, seems to have assimilated layers of early Svionian metabasites, as especially evident from a comparison with the preserved inclusions of these rocks (Table 5). Furthermore, a femic gneiss-granite associated with the Hedesunda granite seems to have become largely admixed with rising basic magma (see Table 8 and p. 21).

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[1] As for exceptions, see the above discussion of the late Svecofennian granites.

The exclusively peculiar composition of the Tertiary rhyolite in Lake Mien, Kronobergs län (Table 4), is also worth special attention. It should be compared with two analyses given in Table 15, *viz.* Ordovician limestone, Gräsgård, Öland, and post-Glacial sand, Skärplinge, Uppsala län. Both these analyses will be discussed below. Owing to its lack of cobalt and its simultaneous enrichment in zinc, the Mien rhyolite can possibly be interpreted as a derivative of some kind of sediment admixed with organic matter and thus showing organic enrichment in nickel (compare below).

I have already mentioned (p. 18) that the low content of chromium characterizing most part of the Swedish bed-rock is reflected in the compositions of the sediments derived from there. Sediments very low in magnesium and iron, such as quartz sands and sandstones, quartzites and pure limestones, should of course be expected to be lacking in all trace elements characteristic of femic minerals (*cf.* Table 15), even if exceptions from this rule will frequently be met with in sedimentary derivatives of rocks extraordinarily high in a certain 'femic' trace element, such as chromium (see p. 16).

On the other hand, quartz and lime sediments altered by weathering or admixed with organic matter may show highly variable contents of certain 'femic' trace elements, as especially evident from Table 15: red, Ordovician limestone, Gräsgård, Öland, and post-Glacial sand, Skärplinge, Uppsala län. The former has enriched chromium, cobalt and nickel up to nine times as compared with the ordinary Ordovician limestone highest in these three metals, *viz.* that of Lovene, Skaraborgs län. Now, the Gräsgård limestone shows special petrographical characteristics including high local enrichments in iron. According to P. Thorslund (Thorslund and Westergård 1938, p. 34), these characteristics should indicate an occasional elevation of the limestone above the sea level during Ordovician time and a resultant surface weathering (see also G. Kautsky 1949, p. 274 *ff.*).

Furthermore, the Gräsgård limestone shows a high numeric value of the quotient Ni : Co, 13. A similar enrichment in nickel as compared with cobalt characterizes the sand at Skärplinge, which has, indeed, been cultivated for many years and has thus been highly contaminated with organic matter. A considerable enrichment in zinc has also been found in this sand. However, as I have shown earlier (P. H. Lundegårdh 1947 b), zinc plays an important rôle in plant and animal nutrition.

The Ordovician limestones in part derive from dead sea animals. The above enrichment in nickel as compared with cobalt would thus be to some extent physiological, although we have to remember that the Ordovician sea water, from which the limestone has precipitated, most probably in itself contained more nickel than cobalt (*cf.* the composition of recent sea water, p. 29). Researches by Mitchell and by I. and W. Noddack also show the existence of enrichments in nickel which are obviously physiological. Mitchell (1946, p. 366) investigated a Scottish herbage and obtained there the following data (dry matter):

| | Cr | Co | Ni | Zn |
|---|---|---|---|---|
| Mixed plants | 0.13 | 0.19 | 1.4 | 43 |
| Red clover | 0.09 | 0.21 | 1.6 | 42 |
| Rye grass | 0.21 | 0.09 | 0.1 | 34 |
| Cocksfoot | 0.12 | 0.05 | 0.1 | 22 |
| Blank | 0.04 | $< 0.01$ | 0.05 | $< 1$ |

We observe that the quotient Ni : Co of red clover is seven times higher than that of rye grass, although both plants have grown on the same soil.

However, on addition of 2 lbs. of cobalt chloride per acre (about 0.25 Co), the uptake by red clover changed markedly (analyses of dry matter; Mitchell 1946, p. 367):

| | No cobalt added | | Cobalt added | |
|---|---|---|---|---|
| | Co | Ni | Co | Ni |
| Unlimed field | 0.22 | 2.0 | 0.89 | 1.6 |
| Limed field[1] | 0.18 | 1.4 | 0.53 | 1.0 |

In view of these data, it seems probable that the uptake of cobalt and nickel is a mere adsorption phenomenon. It should thus be regulated by the general availability of six-coordinated divalent ions showing moderate ionic radii. The influence of lime upon the soil acidity can also be studied in the above table: the decreased uptake of cobalt and nickel by red clover grown on a limed field.

Mitchell's above investigations were entered upon as a consequence of a cobalt deficiency disease in Scottish sheep. Where cobalt deficiency is serious, deaths among lambs are common. On the other hand, lambs manured with cobalt may show live-weight increases of 20 à 30 lbs. at an age of six months, when compared with lambs that have survived without cobalt manuring (Mitchell 1946, pp. 366—67).

These data indicate that cobalt should be necessary for most higher land animals. It is then surprising that the sea animals investigated by I. and W. Noddack (1939, pp. 32—33) are in part so very high in nickel as compared with cobalt (analyses of dry matter, when nothing else is stated whole animals):

| Animal | Cr | Co | Ni | Zn |
|---|---|---|---|---|
| Ascidia: *Ciona intestinalis* | — | 2.3 | 16 | 330 |
| Sponges: *Halichondria* | 0.2 | 0.05 | 22 | 150 |
| Acaleptes (jellyfishes): *Cyanea capillata* | 1.3 | 7.1 | 30 | 1,550 |
| Actinias (sea-anemones): *Metridium dianthus* | — | 1.7 | 23 | 1,400 |
| Holothurias (sea-slugs): *Stichopus tremulus*, bowels | 0.9 | 1.2 | 38 | 140 |
| Echinoids (sea-urchins): *Brissopsis lyrifera*, shells | 0.02 | 2.0 | 2.1 | 65 |
| Asteroids (starfishes): *Asterias rubens*, bowels | 0.02 | 0.9 | 24 | 160 |
| Labridæ (wrasses): *Ctenolabrus rupestris* | — | 3.8 | 30 | 140 |
| Selachians (sharks): *Squalus acanthius*, bowels | 0.2 | 0.1 | 0.3 | 155 |
| Sea water | $< 0.2 \times 10^{-3}$ | $0.1 \times 10^{-3}$ | $0.5 \times 10^{-3}$ | $14 \times 10^{-3}$ |

As is seen, the value of the quotient Ni : Co in recent sea water amounts to 5. In four of the above animals, the value of the quotient exceeds 10, however, and in *Halichondria* it is as high as 440.

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[1] 5 tons of ground limestone per acre.

As chromium, cobalt, nickel and zinc accompany magnesium and iron in the silicate phase, high contents of these four elements should be characteristic of mechanical sediments in part derived from femic minerals, *viz.* clayish sediments. The analyses given in an earlier section of this paper (pp. 15—16) also agree with this statement. Furthermore, the composition of each special clay examined should depend on the average composition of the mother rocks, as displayed by the three analyses of Scottish soils earlier quoted (p. 16).

We have seen that the Swedish bed-rock is on the whole very low in chromium. Accordingly, the resultant clayish sediments are extraordinarily low in this metal (Table 16. Compare the analyses given on pp. 15—16). As a matter of fact, only four samples of the Tyrrhenian sediments analysed by Landergren bear evidence of a similar lack of chromium (p. 15). On the other hand, the Swedish bed-rock contains considerable quantities of zinc. Enrichment in zinc is also characteristic of Swedish clayish sediments (Table 19).

The contents of cobalt and nickel encountered in Swedish clayish sediments are on the whole somewhat higher than the corresponding figures of sediments from other parts of Europe (pp. 15—16, Tables 18 and 20). The values of the quotient Ni : Co are approximately the same, however:

| Character | Ni : Co |
|---|---|
| Sediments from the Tyrrhenian Sea (Landergren; see p. 15) | 1.5 |
| Scottish schists (Mitchell; see p. 15) | 2.3 |
| Finnish schists (Sahama; see p. 16) | 2 |
| Swedish clays and silts, Glacial, single varves (Table 10) | 1.8 |
| Swedish clay slates, shales and clays (Table 11) | 2.2 |
| Swedish clayish sediments, high-metamorphic (Table 12) | 2.2 |

In Swedish clayish sediments, the order of distribution of the four trace elements determined by the writer is as a rule as follows (*cf.* Table 20):

$$\mathrm{Cr} < \mathrm{Co} < \mathrm{Ni} < \mathrm{Zn}.$$

I shall now give a more detailed survey of various Swedish clayish sediments.

In Table 10, we find a series of analyses of single varves of Glacial clay. As would be expected, the winter varves — clay high in $\Sigma$(Mg,Fe) and significantly admixed with organic matter (see G. Arrhenius 1947, p. 57 *ff.*), are higher in all four trace elements determined when compared with the summer varves — silt moderate in $\Sigma$(Mg,Fe) and as rule very poor in organic matter. The admixture with organic matter encountered in the winter varves seems to have influenced the values of the quotients Ni : Co, as evident from the following table (for details, see Table 10):

| Locality | Ni : Co, summer | Ni : Co, winter |
|---|---|---|
| Mestaängen | 1.3 | 1.5 |
| Near Lars Olsbo | 1.7 | 2.4 |
| Hedemora | 1.9 | 2.5 |
| Landsbro | 2.7 | 2.8 |
| Vallsta | 0.8 | 1.1 |
| Gråda | 1.0 | 1.8 |

Although the differences are in part very small, all winter varves analysed show higher values of the quotient than the corresponding summer varves, in harmony with the physiological adsorption of nickel earlier mentioned (p. 28).

Even in high-metamorphic derivatives of Swedish clays and silts, such as the Svionian veined gneisses (and associated leptites) of Södermanlands and Stockholms län (Table 12), the order of distribution of the four trace metals determined is Cr $<$ Co $<$ Ni $<$ Zn. Furthermore, the contents of each special one of these metals correspond surprisingly well to the figures determined on low- and non-metamorphic sediments (Tables 16—20). Indeed, there would seem to be reasons to believe that the veined gneisses analysed have not altered chemically after their sedimentation. The coarse re-crystallization texture and the pegmatite veins should have developed by sinking, re-heating and partial fusion of the sediments.

However, Magnusson (1936 b, p. 70), who investigated in detail the Kantorp ore district in Södermanlands län (represented by two analyses in Table 12), could show that solutions and probably also gaseous 'emanations' from the deeper fused parts of the crust have penetrated the whole district and have altered its primary sediments so as to remove certain elements and deposit other instead of these (metasomatism). Magnusson assumes that the solutions and 'emanations' are granitic. In accordance with this assumption, the pegmatite veins also show transitions into larger masses of palingenic pegmatite. From the latter we have further gradations into palingenic granites which have been classed as equivalents to the late Svionian granites of Central Sweden.

According to Magnusson, the veined gneiss complex of Södermanlands and Stockholms län should thus display a section through a region which was highly changed by migrations and replacements of various elements during late Svionian time. A chemical survey of various veined gneisses given by Sundius (1947, p. 25) supports this interpretation (highly variable compositions, indeed), though we have here to remember that not only clayish sediments but also acid volcanics and Svecofennian granites are included in the veined gneiss complex (Magnusson 1936 b, Sundius 1947).

Sundius (1947) has investigated the veined gneisses of Stockholms län. He interprets these as metasomatic sediments, in principal accordance with the above scheme. However, Sundius postulates a Svecofennian origin of the agents producing the veined gneisses. The pegmatite veins should thus have crystallized from residual solutions developed by the congealing Svecofennian basite and granite magmas.

In Central Roslagen, investigations by the writer (P. H. Lundegårdh 1946 a, pp. 97—101) have shown that the pegmatites and veined gneisses are younger than the post-Svecofennian meta-basites mentioned on p. 22, in harmony with Magnusson's conception.

An example of wholly palingenic clay or silt will be found close to the end of Table 2, I. The grey Svecofennian granite from Gladtjärnberget, Kopparbergs län, there represented runs as follows:

$$Cr \leqslant 1, \ Co = 20, \ Ni = 30, \ Zn = 200.$$

According to Hjelmqvist (1937, p. 42), this rock should have developed by fusion and mobilization of sediments belonging to the Larsbo series. We shall now consider a sample of such a silt, high-metamorphic though *not* metasomatic, and taken from an outcrop not very far from Gladtjärnberget, *viz.* mica schist from Stora Norn, Kopparbergs län (Table 12):

$$Cr = 2, \ Co = 20, \ Ni = 30, \ Zn = 100.$$

The distributions and concentrations of all four trace metals determined have apparently remained fairly constant during the palingenesis. In view of this experience, it will be clear that the 'purely clayish' distribution of chromium, cobalt, nickel and zinc characterizing the veined gneisses above described cannot be regarded as an evidence against metasomatic alterations of the original sediments. The distribution encountered merely shows that the four trace metals analysed have been comparatively immobile during the palingenesis.

As regards chromium, cobalt and nickel, this immobility is not surprising (see p. 22), whereas, in the case of zinc, an evaporation would have been expected. When studying in detail Table 12, we also find Svionian veined gneisses that seem to have evaporated considerable amounts of zinc, such as the rock NE of Lagmansö, Södermanlands län. In view of the areal distribution of the Svionian veined gneisses, an average evaporation of 50 zinc should have been sufficient to produce local enrichments into ores outside the palingenic region (10 × 10 × 10 m veined gneiss should then have given 150 kg Zn). This quantity corresponds to about 20 % of the mean concentration of zinc in Swedish clayish sediments free or almost free from organic matter. Furthermore, we seem to have had a supply of zinc during the palingenesis evaporated from deeper parts of the crust (Magnusson: lecture before the Geological Society of Stockholm, 1948). Part of this supply should have compensated more or less of the zinc lost by the veined gneisses themselves, part of it should have joint the evaporates of the veined gneisses and thus contributed to the development of zinc ores outside the palingenic region. As also pointed out by Magnusson (lecture cited), such an extensive deposit of zinc ore as that of Åmmeberg is situated immediately SW of the Svionian veined gneiss complex (near Askersund in Örebro län).

At the end of Table 12, we find a high-metamorphic clay slate which seems to be Gotho-Karelian, *viz.* the biotite gneiss SSW of Jävre, Norrbottens län. According to E. Åhman (personal communication), this gneiss belongs to the same strata as the mica schist near Hamntjärn (see also Table 12) and the graphite-pyrite-bearing slate of the Kalix skerries, Norrbottens län (Table 13). We might therefore expect it to contain considerable amounts of zinc, 200 à 300. However, the real content is only 50, most probably owing to evaporation during the metamorphism.

In Table 13, I have given a number of clay sediments admixed with significant quantities of organic matter. Of these, the post-Glacial clays analysed have been cultivated for many years. As would be expected, the concentrations of the four trace elements determined are highly variable all through the table. Thus, for instance, the graphite-pyrite-bearing black slate of the Kalix skerries, Norrbottens län, shows a considerable enrichment in nickel, whereas the Cambrian *Tessini* shale at Borgholm, Öland, is extraordinarily high in zinc. Further, it should be noted that the values of the quotient Ni : Co are frequently very high and on an average $\geq 4$, whereas they do not seem to exceed 2.5 in normal clays (p. 30). These high values are most probably due to organic enrichment by adsorption (compare pp. 28—29).

In Table 14, we find two analyses of leached Mesozoic clays. These are extraordinarily low in magnesium (MgO varies between $< 0.2$ and 0.46 %[1]). They also show a marked decrease of nickel, and one of them contains very little chromium. The concentrations of cobalt and zinc are normal, in spite of the low contents of iron (Fe determined as $Fe_2O_3 = 0.7—2.1$ %[1]).

The alteration by leaching thus exemplified is very important, as it has resulted in a distribution of chromium, cobalt and nickel which is similar to that encountered in late-magmatic compounds (compare Tables 5 and 14). Furthermore, the leaching has resulted in a relative increase of iron as compared with magnesium, though the total contents of both metals have diminished in the samples analysed. This observation opens new views. Indeed, it seems to be possible to obtain false 'late-magmatic rocks' by metasomatism of sediments, *nota bene* if considerable quantities of iron are introduced during the metasomatism so as to make the whole sediments sufficiently basic. The necessary immigration of iron should occur in connection with granitizations of sediments containing layers of iron ore.

Earlier we have observed that various clay sediments outside Sweden, for ex. in Finnish Lappland (p. 16), are high in chromium, actually showing the 'first-magmatic' order of distribution of chromium, cobalt and nickel: $Cr > Ni > Co$. Obviously, such sediments, on addition of magnesium, may give origin to false 'first-magmatic' basites. Simultaneously, equivalent amounts of silicon and aluminum should of course be removed. As magnesium is most frequently accompanied by nickel, the rather low primary contents of nickel encountered in the clay sediments mentioned will easily rise enough to make the metasomatic basite puzzlingly like a magmatic one. The mobility of magnesium is well known from investigations by Eskola (1914) and Geijer (1917, 1923), further by Magnusson (1925) and Hjelmqvist (1937).

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[1] A. Lundegren 1931, p. 309, and unpublished analyses received from Höganäs-Billesholms AB by the courtesy of Dr. R. Norin.

## Literature Cited.

BGIU = Bull. of the Geol. Instit. of the University of Upsala.
GFF = Geol. Föreningens i Stockholm Förhandlingar.
SGU = Sveriges Geologiska Undersökning (Geol. Survey of Sweden).

ARRHENIUS, G., Den glaciala lerans varvighet. Summary: The Varvity of the Glacial Clay. SGU Ser. C, no. 486, *1947*.

ASKLUND, B., Berggrunden i Beskrivning till kartbladet Torönsborg. SGU Ser. Aa, no. 153, *1923*.

—, Petrological Studies in the Neighbourhood of Stavsjö at Kolmården. SGU Ser. C, no. 325, *1925*.

BACKLUND, H. G., Die Umgrenzung der Svecofenniden. BGIU XXVII, *1937*.

—, Die ältesten Baueinheiten von Fennoskandia. Mitt. d. Nat.-forsch. Gesellsch. Schaffhausen XVII, *1941*.

—, Einblicke in das geologische Geschehen des Präkambriums. Geol. Rundschau 34, *1943*.

BRUNDIN, N. H., see GOLDSCHMIDT 1938, pp. 81—82.

CLARKE, F. W., The Data of Geochemistry. 5th ed. U. S. Geol. Survey, Bull. 770, *1924*.

—, and H. S. WASHINGTON, The Composition of the Earth's Crust. U. S. Geol. Survey, Prof. Paper 127, *1924*.

DU RIETZ, T., Peridotites, Serpentines, and Soapstones of Northern Sweden. GFF 57, *1935*.

ESKOLA, P., On the Petrology of the Orijärvi Region in Southwestern Finland. Bull. Comm. géol. Finlande 40, *1914*.

GEIJER, P., On the Intrusion Mechanism of the Archean Granites of Central Sweden. BGIU XV, *1916*.

—, Falutraktens berggrund och malmfyndigheter. German summary. SGU Ser. C, no. 275, *1917*.

—, Riddarhytte malmfält. English summary. Kungl. Kommerskoll., beskrivn. över mineralfyndigheter 1, *1923*.

—, Magmagaserna som förmedlare av regional metasomatisk omvandling. GFF 56, *1934*.

GOLDSCHMIDT, V. M., Geochemische Verteilungsgesetze der Elemente, IX. Die Mengenverhältnisse der Elemente und der Atom-Arten. Skr. utg. av Det Norske Vid.-Akad. I. Mat.-Naturvid. Kl., *1938*.

—, The Geochemical Background of Minor-Element Distribution. Soil Science 60, *1945*.

HJELMQVIST, S., Berggrunden i Beskrivning till kartbladet Smedjebacken. SGU Ser. Aa, no. 181, *1937*.

—, Über Sedimentgesteine in der Leptitformation Mittelschwedens. SGU Ser. C, no. 413, *1938*.

—, Stribergs malmfält. German summary. SGU Ser. C, no. 449, *1942*.

KAUTSKY, G., Stratigraphische Grundzüge im westlichen Kambrosilur der skandinavischen Kaledoniden. GFF 71, *1949*.

KROKSTRÖM, T., The Breven Dolerite Dike. BGIU XXIII, *1932*.

LANDERGREN, S., Geokemiska studier över Grängesbergsfältets järnmalmer. English summary. Ingenjörsvetenskapsakad., Stockholm: Proceedings 172, *1943*.

—, On the Geochemistry of Swedish Iron Ores and Associated Rocks. A Study on Iron-Ore Formation. SGU Ser. C, no. 496, *1948 a*.

—, On the Geochemistry of Mediterranean Sediments: Prel. Report on the Distribution of Beryllium, Boron and the Ferrides in Three Cores from the Tyrrhenian Sea. Medd. från Oceanografiska institutet i Göteborg 15, *1948 b*.

LARSSON, W., Några resultat av berggrundsgeologiska studier inom Dalformationens norra gränsområde. GFF 69, *1947*.

LUNDEGREN, A., De kretaceiska ler- och sandförekomsterna N om Ivösjön. German summary. GFF 53, *1931*.

LUNDEGÅRDH, P. H., Bytownit aus Anorthosit von Bönskär. BGIU XXVIII, *1941*.

—, The Grovstanäs Region. BGIU XXIX, *1943*.

—, Rock Composition and Development in Central Roslagen, Sweden. Arkiv f. kemi, mineralogi o. geologi utg. av K. Svenska Vetenskapsakad. 23 A, no. 9, *1946 a*.

—, Geochemistry of Magmatic Iron Ore. Nature 157, no. 3993, *1946 b*.

—, Den ultrabasiska gabbron i Roslagen. Summary: The Ultra-Basic Gabbro of Roslagen, Central Sweden. SGU Ser. C, no. 484, *1947 a*.

—, Some Aspects to the Determination and Distribution of Zinc. Ann. of the Royal Agricultural Coll. Sweden 15, (1948) *1947 b*.

MAGNUSSON, N. H., Persbergs malmtrakt och berggrunden i de centrala delarna av Filipstads bergslag. English summary. Kungl. Kommerskoll., beskrivn. över mineralfyndigheter 2, *1925*.

—, Om cykelindelningen i det svenska urberget. GFF 58, *1936 a*.

—, Berggrunden inom Kantorps malmtrakt. Summary: The Veined Gneisses of the Kantorp Ore District. SGU Ser. C, no. 401, *1936 b*.

—, Herrängsfältet och dess järnmalmer. Summary: The Herräng Field and its Iron Ores. SGU Ser. C, no. 431, *1940*.

MITCHELL, R. L., Applications of Spectrographic Analysis to Soil Investigations. The Analyst 71, no. 845, *1946*.

—, see NOCKOLDS and WAGER.

NOCKOLDS, S. R., The Garabal Hill—Glen Fyne Igneous Complex. The Quarterly Journ. of Geol. Soc. 96, (1940) *1941*.

—, and R. L. MITCHELL, The Geochemistry of Some Caledonian Plutonic Rocks. Trans. of the Royal Soc. Edinburgh LXI, part II (no. 20), *1948*.

NODDACK, I. and W., Die Häufigkeiten der Schwermetalle in Meerestieren. Arkiv f. zoologi utg. av K. Svenska Vetenskapsakad. 32 A, no. 4, *1939*.

PAULING, L., The Nature of the Chemical Bond and the Structure of Molecules and Crystals. 2d ed. *1940*.

RANKAMA, K., On the Geochemical Differentiation in the Earth's Crust. Bull. Comm. Géol. Finlande 137, *1946*.

ROSENQVIST, I. TH., Diffusjonskoeffisienten for bly i noen radioaktive mineraler. English summary. GFF 71, *1949*.

SAHAMA, TH. G., Spurenelemente der Gesteine im Südlichen Finnisch-Lappland. Bull. Comm. Géol. Finlande 135, *1945 a*.

—, On the Chemistry of the East Fennoscandian Rapakivi Granites. Compt. Rend. de la Soc. géol. Finlande XVIII, *1945 b*.

SANDELL, E. B., and S. S. GOLDICH, The Rarer Metallic Constituents of some American Igneous Rocks I—II. J. of Geology LI, *1943*.

STILLE, H., Einführung in den Bau Amerikas, *1940*.

SUNDIUS, N., Grythyttefältets geologi. English summary. SGU Ser. C, no. 312, *1923*.

SUNDIUS, N., Berggrunden inom sydöstra delen av Stockholms skärgård. Summary: Rocks in the Southeastern Part of the Stockholm Archipelago. SGU Ser. C, no. 419, *1939*.

—, Femisk leptit och slirgnejs. Summary: Femic Leptite and Veined Gneiss. SGU Ser. C, no. 488, *1947*.

—, Beskrivning till berggrundskarta över Stockholmstrakten. SGU Ser. Ba, no. 13, *1948*.

THORSLUND, P., and A. H. WESTERGÅRD, Deep Boring through the Cambro-Silurian at File Haidar, Gotland. SGU Ser. C, no. 415, *1938*.

TRYGGVASON, T., Das Skjaldbreiðgebiet auf Island. BGIU XXX, *1943*.

VOGT, J. H. L., On the Average Composition of the Earth's Crust. Skr. utg. av Det Norske Vid.-Akad. I. Mat.-Naturvid. Kl., *1931*.

WAGER, L. R., and W. A. DEER, The Petrology of the Skaergaard Intrusion, Kangerdlugssuak, East Greenland. Medd. om Grønland 105, no. 4, *1939*.

—, and R. L. MITCHELL, Prel. Observations on the Distribution of Trace Elements in the Rocks of the Skaergaard Intrusion, Greenland. Min. Mag. XXVI, *1943*.

—, and R. L. MITCHELL, Distribution of Vanadium, Chromium, Cobalt, and Nickel in Eruptive Rocks. Nature 156, no. 3955, *1945*.

WAHL, W., Om granitgrupperna och bergskedjeveckningarna i Sverige och Finland. GFF 58, *1936*.

WASHINGTON, H. S., see CLARKE.

WEGMANN, E., Über alpine Tektonik und ihre Anwendung auf das Grundgebirge Finnlands. Compt. Rend. de la Soc. géol. Finlande 3, *1929*.

—, Zur Deutung der Migmatite. Geol. Rundschau 26, *1935*.

WICKMAN, F. E., Some Aspects of the Geochemistry of Igneous Rocks and of Differentiation by Crystallization. GFF 65, *1943*.

# Tables.

## Table 1.[0] Early Svionian and Gotho-Karelian, acid volcanics and sediments, high-metamorphic (leptites,[1] leptite gneisses,[1] fine-grained gneisses), in approximate order of relative age.

| Early Svionian | | | | | |
|---|---|---|---|---|---|
| Character | Locality | Cr | Co | Ni | Zn |
| Leptite gneiss, grey[2]. LS. | Quarry 1.5 km E of Hyttön, parish of Älvkarleby, Uppsala län. | $<1$ | $<2$ | $<1$ | $\leq 50$ |
| Do., bluish grey[2]. LS. | 1200 m S—SSE of Flät, do., do. | 1 | $<1$ | $<1$ | $\leq 50$ |
| Do., pale grey, quartz-porphyritic[2]. LS. | ESE of Forsbacka, parish of Valbo, Gävleborgs län. | $\leqslant 1$ | $<1$ | $\leqslant 1$ | $\leq 50$ |
| Gneiss, reddish grey, hornblende-bearing. LS. | At the roadway 2 km S of Glamsen, parish of Älvkarleby, Uppsala län. | 1 | $<2$ | $<1$ | $\leq 50$ |
| Leptite gneiss, grey red. GS. | Östra Lagnö, parish of Ljusterö, Stockholms län. | 3 | 5 | 20 | 300 |
| Do., grey. LS. | Malsta church, parish of Malsta, Stockholms län. | 5 | 6 | 30 | 100 |
| Layers alternating with do.: leptite, dark grey[2, 3]. LS. | Do., do., do. | 4 | 35 | 25 | 100 |
| Leptite gneiss, grey[3]. GS. | Ekeby NW of Norrtälje, do., do. | 20 | 20 | 8 | 200 |
| Do., dark grey[3]. LS. | 2.5 km ENE of Kubbo, parish of Valbo, Gävleborgs län. | 3 | 5 | $<1$ | 150 |
| Leptite, dark grey[3]. GS. | Easternmost part of Central Ladholmen, parish of Djurö, Stockholms län. | 2 | 5 | $\leq 2$ | $<25$ |
| Do., do.[2,3]. LS. | Strömskär, Ladholmen, do., do. | 4 | $<1$ | 30 | $<15$ |
| Do., do.[2,3] LS. | Islet SE of Stora Limskär, do., do. | 15 | $<1$ | 60 | $<15$ |
| Do., do[3]. GS. | Grönvik, Nämdö, parish of Nämdö, Stockholms län. | 3 | 15 | 15 | $<50$ |
| Do., do[3]. GS. | Orrön SE of Nämdö do., do. | 5 | 15 | 40 | $<25$ |
| Do., do[3]. LS. | Trätskär E of Nämdö, do., do. | 5 | 15 | 100 | 50 |
| Sandy slate[2], pale grey, thin layer close below femic leptite, LS. | 1.5 km WSW of Skogen, at the roadway Älvkarleö—Hyttön, parish of Älvkarleby, Uppsala län. | 2 | $<1$ | $<1$ | $\leq 50$ |
| Gneiss, reddish grey. LS. | Glamsen, do., do. | 1 | 5 | $<1$ | 150 |
| Leptite gneiss, femic, dark grey. LS. | 1.5 km WSW of Skogen, at the roadway Älvkarleö—Hyttön, do., do. | $\leqslant 1$ | $<1$ | $\leqslant 1$ | 200 |
| Do., do., do., high in hornblende[4]. LS. | 1 km WNW of Mohäll, parish of Valbo, Gävleborgs län. | $<1$ | 10 | 1 | 200 |

| Early Gotho-Karelian | | | | | |
|---|---|---|---|---|---|
| Character | Locality | Cr | Co | Ni | Zn |
| Gneiss[5], dark grey. LS. | 3 km S of Vitåfors, parish of Råneå, Norrbottens län. | 3 | 3 | 3 | $<15$ |
| Palingenic derivative of do.: granite, red grey to grey, coarse to fine medium-grained. GS. | Parishes of Hortlax, Kalix, Nederluleå, Råneå and Töre, Norrbottens län. | 3 | 2 | 3 | 50 |
| Gneiss[2], grey red ('iron gneiss'). GS. | Hulebäckseröd, parish of Hjärnarp, Kristianstads län. | $<1$ | $<2$ | $<1$ | 50 |

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[0] In this and following tables, GS means general sample and LS local sample (*cf.* p. 6). All concentrations of trace elements are given in parts per million. Analyst: P. H. Lundegårdh.

[1] Fine-grained rocks (more fine-grained than ordinary gneisses).

[2] $SiO_2 \geq 70$ %.

[3] The plagioclase contains $\geq 30$ % An.

[4] Grading into amphibolite (*cf.* Table 5).

[5] Possibly Svionian.

## Table 2. Svecofennian granites ('urgranites').[0]

| I. Main fraction | | | | | |
|---|---|---|---|---|---|
| Character | Locality | Cr | Co | Ni | Zn |
| Gneiss-granite, grey. LS. | E of Lycksjön, S of Vendelsö, parish of Österhaninge, Stockholms län. | 1 | <1 | 1 | 120 |
| Do., do. LS. | Handen, do., do. | <1 | 0 | <1 | 150 |
| Do., do. LS. | Pålsundet near Vaxholm, Stockholms län. | 20 | 25 | 10 | 100 |
| Quartz-syenite, grey. GS. | Östanå, parish of Roslags-Kulla, Stockholms län. | 14 | 13 | 6 | 250 |
| Gneiss-granite, grey. GS. | 2 km NW of Vättershaga, parish of Länna, Stockholms län. | 11 | 15 | 7 | 180 |
| Do., do. GS. | Bergshamra, do., do. | 10 | 21 | 22 | 200 |
| Do., do. GS. | 2.5 km E of Bergshamra, do., do. | 12 | 30 | 20 | 140 |
| Do., do. GS. | 500 m SE of Grovstanäs, do., do. | 4 | 8 | 10 | 150 |
| Do., do., dioritic, sometimes garnet-bearing. GS. | 1 km NE of Hysingsvik, parish of Frötuna, Stockholms län. | 4 | 10 | 8 | 180 |
| Do., do., syenitic, in part porphyritic (pink microcline eyes)[1]. GS. | Road-cutting 800 m E of Hysingsvik, parish of Länna, Stockholms län. | 4 | 2 | ⩽1 | 110 |
| Dioritic granite, grey. GS. | Road-cutting 1 km NW of Penningby, do., do. | 4 | 15 | 10 | 180 |
| Gneiss-granite, grey, dioritic, porphyritic (plagioclase eyes). GS. | 1750 m NE of Penningby, do., do. | 6 | 6 | 6 | 200 |
| Dioritic granite, grey, garnet-bearing. GS. | 2 km NW of Penningby, do. do. | 0 | 4 | 2 | 210 |
| Gneiss-granite, grey. GS. | Quarry 5 km S of Norrtälje, parish of Frötuna, Stockholms län. | 6 | 6 | 3 | 240 |
| Quartz-diorite[2], dark grey. GS. | 4.5 km SSW of Norrtälje, do., do. | 4 | 30 | 8 | 160 |
| Gneiss-granite, grey, very high in microcline[3]. GS. | Quarry 5 km SE of Norrtälje, do., do. | 3 | 5 | 4 | 250 |
| Gneiss-granite, grey. GS. | Road-cutting near Notsta, do., do. | 5 | 14 | 25 | 100 |
| Do., do. GS. | Quarry in the NE suburbs of Norrtälje, Stockholms län. | 1 | 2 | 3 | 50 |
| Do., do. GS. | Ilsholmen, parish of Roslags-Bro, Stockholms län. | 1 | 5 | 3 | 50 |
| Granite, grey (Uppsala granite). GS. | Ekeby W of Uppsala, Uppsala län. | 25 | 45 | 20 | 200 |
| Gneiss-granite, grey, dioritic. LS. | 300 m NW of Bergavallen, parish of Årsunda, Gävleborgs län. | <1 | 5 | 2 | 110 |
| Granite[4], reddish greenish grey. LS. | 500 m NE of Stora Hästtjärn, parish of Söderbärke, Kopparbergs län. | 1 | 10 | 3 | 300 |
| Gneiss-granite, grey. GS. | 350 m SW of Klockarbo, do., do. | 2 | 15 | 4 | 200 |
| Granite, grey. GS. | S part of Gladtjärnberget, do., do. | ⩽1 | 20 | 30 | 200 |
| Gneiss-granite[5], grey. GS. | Near Nytäppan, WSW of Smedjebacken, parish of Norrbärke, Kopparbergs län. | ⩽1 | 5 | ⩽1 | 40 |

(Continued)

**Table 2.** (Continued).

II. Late varieties[6]

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Gneiss-granite, red grey, porphyritic (pink microcline eyes; Vaxholm granite). LS. | Hasselkubben 6 km WNW of Sandhamn, parish of Djurö, Stockholms län. | 4 | 1 | 2 | 150 |
| Do., do., do. GS. | 2.5 km ESE of Penningby, parish of Länna, Stockholms län. | 2 | 2 | 1 | <5 |
| Do., grey red, porphyritic (red microcline eyes). GS. | 2 km NE of Penningby, do., do. | 3 | 2 | 2 | <5 |
| Gneiss, red, extremely salic. LS. | Villinge, parish of Nämdö, Stockholms län. | ⩽1 | ⩽1 | ⩽1 | 40 |
| Gneiss-granite, red, extremely salic. GS. | 3 km SE of Bergshamra, parish of Länna, Stockholms län. | 2 | ⩽1 | 1 | 10 |
| Do., do., do. GS. | 3 km S of Penningby, do., do. | 2 | ≤1 | 2 | 30 |
| Do., red to grey red (Vänge granite). GS. | Vänge, parish of Vänge, Uppsala län. | 1 | <1 | <1 | 80 |
| Do., grey, porphyritic (grey microcline eyes; Arnö granite). GS. | Gottröra, parish of Gottröra, Stockholms län. | <1 | <2 | <1 | 40 |
| Quartz-syenite, red grey to red, porphyritic (red microcline eyes). GS. | Österskär, parish of Österåker, Stockholms län. | <1 | <1 | <1 | 190 |

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[0] Fine- to medium-grained rocks; the microcline eyes of the porphyritic varieties most frequently coarse.

[1] Grading into Vaxholm granite (compare below).

[2] Granite basified by assimilated metabasite (*cf.* Table 5).

[3] 24 %.

[4] Dike in metabasite (see Table 5).

[5] Dikes in uralite-gabbro (see Table 6).

[6] Including members of the main fraction high in secondary microcline eyes (Vaxholm granite).

**Table 3. Post-Svecofennian, pre-Algonkian granites, in order of relative age.**

I. Svionian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Granite, red, medium-grained (Vätö granite). GS. | Vätö, parish of Vätö, Stockholms län. | 1 | ≤1 | ≤1 | <5 |
| Do., do., do. GS. | Dåderholmen SSE of Grovstanäs, parish of Länna, Stockholms län. | 1 | <1 | 1 | <5 |
| Aplite-granite[1], red, fine-grained. GS. | 600 m SW of Hysingsvik, do., do. | 1 | <1 | 2 | <5 |
| Granite, red, medium-grained (Vätö granite). GS. | Road-cutting near Roslags-Kulla, parish of Roslags-Kulla, do. | 1 | <1 | 1 | <15 |
| Granite, grey red, in part coarse, porphyritic (microcline eyes; Hedesunda granite). LS. | 200 m E of the railway, SW of Sällvallen, parish of Hedesunda, Gävleborgs län. | ⩽1 | ≤1 | ⩽1 | ≤50 |
| Do., do., do., do. LS. | Hornberget, parish of Årsunda, Gävleborgs län. | 0 | <1 | ⩽1 | 150 |
| Granite, grey red, in part coarse, syenitic (Hedesunda granite). LS. | 1.5 km N of Gillerås, parish of Hedesunda, Gävleborgs län. | ⩽1 | 3 | ⩽1 | 75 |
| Syenite[2], pink, in part coarse, porphyritic (microcline eyes). LS. | 2 km ESE of Hyttön, parish of Älvkarleby, Uppsala län. | ⩽1 | ⩽1 | ⩽1 | ≤30 |
| Granite, red grey, fine-grained (Malingsbo granite). LS. | 1800 m NNE of Nybo, parish of Hedesunda, Gävleborgs län. | <1 | <1 | <1 | 80 |
| Granite, grey, medium-grained (Revsund granite?). GS. | Nasafjäll, parish of Arjeplog, Norrbottens län. | 2 | <1 | <1 | 150 |
| Granite, grey, fine-grained (Stockholm granite). GS. | Experimentalfältet, Stockholm. | 3 | 1 | 2 | <5 |
| Do.[3], do., do. GS. | 3 km N of Penningby, parish of Frötuna, Stockholms län. | 1 | <1 | 1 | 50 |
| Do.[4], do., do., aplitic. LS. | Quarry 5 km S of Norrtälje, do., do. | 3 | 1 | 10 | <5 |

II. Gotho-Karelian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Granite, red violet, medium-grained (Växjö granite). GS. | Orrefors, parish of Hälleberga, Kronobergs län. | 2 | <2 | <1 | 50 |
| Do., grey red, femic, in part coarse, porphyritic (microcline eyes; Filipstad granite). GS. | Filipstad, Värmlands län | 4 | ≤2 | <1 | 170 |
| Do., do., intermediate, do., do. GS. | 700 m S of Dennicketorp, parish of Filipstad, Värmlands län. | 2 | <2 | 5 | 200 |
| Granite, grey red, fine medium-grained (Bohus granite). GS. | Quarry in Bovallstrand, parish of Tossene, Göteborgs and Bohus län. | <1 | <1 | <1 | 100 |
| Do., do., do. GS. | Brastad, parish of Brastad, Göteborgs and Bohus län. | 1 | <2 | <1 | 100 |

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[1] Dike of Vätö granite in Svecofennian granite.

[2] Dike of Hedesunda granite in late Svionian, femic gneiss-granite (see Table 8).

[3] Dike in metabasite.

[4] Minor dike in Svecofennian granite.

**Table 4. Porphyry, rhyolite and similar acid rocks,[0] in order of relative age.**

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Gotho-Karelian(?) quartz-porphyry, brown red, with quartz and feldspar eyes. LS. | Salto, parish of Jokkmokk, Norrbottens län. | 1 | $<1$ | $<1$ | $\leq 50$ |
| Gotho-Karelian feldspar porphyry[1], red to dark red violet. GS. | Skurugata, parish of Hult, Jönköpings län. | $<1$ | 2 | $<2$ | 170 |
| Sub-Jotnian feldspar porphyry[2], dark violet. GS. | Älvdalen, parish of Älvdalen, Kopparbergs län. | 2 | 2 | $<2$ | 200 |
| Sub-Jotnian granite[3], red, syenitic. GS. | Garberg, do., do. | $<1$ | 2 | $<2$ | 150 |
| Jotnian granophyre, red. GS. | Parishes of Bo and Regna[4], Örebro and Östergötlands län. | 1 | $<1$ | $<1$ | 150 |
| Tertiary rhyolite, grey. GS. | Ramsö, Lake Mien, parish of Urshult, Kronobergs län. | 6 | $\leq 2$ | 50 | $<30$ |

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[0] Aphanitic to fine-grained rocks, most frequently with coarser eyes (the porphyries).

[1] Småland porphyry.

[2] Älvdal porphyry.

[3] Garberg granite, hypabassic, fine- to medium-grained.

[4] E part of the Breven dolerite dike (*cf.* Table 9).

### Table 5. Early Svionian, basic volcanics, high-metamorphic[0].

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Metabasite[1], black, remnant in grey gneiss-granite. LS. | 1 km NE of Hysingsvik, parish of Frötuna, Stockholms län. | 8 | 40 | 35 | 220 |
| Amphibolite, grey black, remnants in grey gneiss-granite. GS. | Road-cutting 700 m ESE of Bergshamra, parish of Länna, Stockholms län. | 2 | 35 | 30 | 180 |
| Do., do., do. GS. | 4.5 km SSW of Norrtälje, parish of Frötuna, Stockholms län. | 1 | 60 | 11 | 400 |
| Do., do., do. GS. | Quarry 5 km S of Norrtälje, do., do | 0 | 70 | 10 | 150 |
| Do., do., do. GS. | Ilsholmen, parish of Roslags-Bro, Stockholms län. | 1 | 23 | 3 | 90 |
| Do., do., do. GS. | ESE of Penningby, S of the W part of Edsviken, parish of Länna, Stockholms län. | 0 | 30 | ⩽1 | 350 |
| Metabasite, reddish grey black, remnant in Hedesunda granite[2]. LS. | 1 km SE of Nynäs, near Fäbodsjön, parish of Hedesunda, Gävleborgs län. | 0 | 15 | <1 | 200 |
| Do., do., altered into quartz-monzonite, do. LS. | 400 m W of Harvbyggvallen, do., do. | 0 | 20 | ⩽1 | 250 |
| Amphibolite, greenish grey black, porphyritic (uralite eyes of medium size). LS. | 2350 m E of Kubbo, parish of Valbo, Gävleborgs län. | 5 | 20 | 20 | 40—50 |
| Do., dark grey, quartz-dioritic. LS. | 250—300 m SSE of Mohäll, parish of Älvkarleby, Uppsala län. | 3 | 50 | 20 | 60—70 |
| Do., grey black, layers alternating with leptite[3]. GS. | Malsta church, parish of Malsta, Stockholms län. | ≤1 | 40 | 15 | 70 |
| Uralite-porphyrite (coarse eyes), black green. GS. | 500 m NE of Stora Hästtjärn, parish of Söderbärke, Kopparbergs län. | <2 | 20 | 10 | 220 |
| Metabasite[4], grey black, layered inclusion in veined gneiss. LS. | 800 m NE of the railway station, Rotebro, parish of Sollentuna, Stockholms län. | 15 | 10 | 70 | 150 |

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[0] The rocks of this table are fine medium- to fine-grained.

[1] 28.5 % quartz, 69.5 % biotite and penninite, 2 % apatite.

[2] Table 3.

[3] Table 1.

[4] Uppermost early Svionian, or 'Bottnian', metabasite, younger than the aforementioned rocks.

**Table 6. Svecofennian basites (basic rocks belonging to the 'urgranite suite'), in order of decreasing contents of chromium.**

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Lherzolite, green black, medium- to fine medium-grained. GS. | Close to the W part of Stora Bårsjön, parish of Möklinta, Västmanlands län. | 800 | 60 | 400 | 100 |
| Gabbro, femic, green black, fine medium-grained. LS. | Ornö huvud (northernmost part of Ornö), parish of Ornö, Stockholms län. | 700 | 65 | 120 | 140 |
| Lherzolite, greenish black, fine- to medium-grained. GS. | W of Klockarbo, parish of Söderbärke, Kopparbergs län. | 650 | 35 | 400 | 80 |
| Uralite-gabbro, green black, fine medium-grained. LS. | Ornö huvud, parish of Ornö, Stockholms län. | 600 | 60 | 180 | 130 |
| Davainite[1], green black, medium-grained to coarse. GS. | N of Torkholm and NW of Jordåsen, parish of Valbo, Gävleborgs län. | 600 | 45 | 120 | 50 |
| Uralite-porphyrite, green black, fine- to medium-grained, coarse eyes. GS. | E end of Stora Bårsjön, parish of Möklinta, Västmanlands län. | 500 | 25 | 160 | 25 |
| Do., do., do., do. GS. | N of the centre of Stora Bårsjön, do., do. | 500 | 60 | 180 | 10 |
| Meta-peridotite, dark yellowish brownish green, fine medium-grained. LS. | Ornö huvud, parish of Ornö, Stockholms län. | 300 | 25 | 150 | 55 |
| Pyroxenite-hornblendite[2], black, medium-grained. LS. | 11 km S of Norrtälje, parish of Länna, Stockholms län. | 150 | 40 | 120 | 250 |
| Uralite-gabbro, grey black green, fine- to fine medium-grained. GS. | Near Nytäppan, WSW of Smedjebacken, parish of Norrbärke, Kopparbergs län. | 150 | 45 | 100 | 50 |
| Do., do., mainly fine-grained. GS. | S part of Vanberget, parish of Söderbärke, Kopparbergs län. | 100 | 60 | 70 | 40 |
| Gabbroic quartz-diorite, grey black green, fine medium-grained. LS. | Grovsta near Penningby, parish of Länna, Stockholms län. | 85 | 40 | 90 | 110 |
| Gabbro, femic, grey black to black, medium-grained. GS. | Vånö, Runmarö, parish of Djurö, Stockholms län. | 50 | 60 | 250 | 130 |
| Gabbroic diorite, grey black, fine medium- to fine-grained. LS. | Ornö huvud, parish of Ornö, Stockholms län. | 50 | 10 | 35 | 35 |
| Uralite-gabbro, grey black green, fine-grained. LS. | Finngården SW of Norn, parish of Hedemora, Kopparbergs län. | 25 | 20 | 80 | 60 |
| Amphibolite[3], grey black to black, fine-grained. LS. | Ornö huvud, parish of Ornö, Stockholms län. | 25 | 10 | 16 | 25 |
| Dioritic gabbro, grey black, medium-grained. GS. | Kastö S of Nämdö, parish of Nämdö, Stockholms län. | 20 | 30 | 17 | 50 |
| Quartz-diorite, grey, fine medium-grained, garnet-bearing. LS. | Islet off the W coast of Hemmarö, parish of Länna, Stockholms län. | 20 | 50 | 30 | 200 |
| Uralite-gabbro, grey black green, fine-grained. GS. | Gladtjärnberget, parish of Söderbärke, Kopparbergs län. | 10 | 35 | 50 | 100 |
| Quartz-diorite, grey, fine medium- to medium-grained. GS. | Ornö, parish of Ornö, Stockholms län. | 10 | 40 | 25 | 70 |
| Diorite, black grey green, fine- to fine medium-grained. LS. | Penningby, parish of Länna, Stockholms län. | 5 | 48 | 75 | 120 |
| Gabbro, grey black, medium-grained. GS. | Ultuna, Uppsala, Uppsala län. | 5 | 32 | 27 | 70 |
| Norite, grey black, fine-grained. GS. | Valsjön, Margretelund, parish of Österåker, Stockholms län. | $\leqslant 1$ | 40 | 60 | 55 |
| Diorite, grey black green, fine medium- to medium-grained. GS. | Solö, parish of Länna, Stockholms län. | 0 | 25 | c | 80 |

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[1] Rock essentially composed of uralite.

[2] Remnants in Svecofennian granite.

[3] Layer in the band series.

**Table 7. Post-Svecofennian, pre-Algonkian, massive ultra-basites, in approximate order of relative age.**

I. Svionian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Anorthosite[1], grey white, medium-grained. GS. | Bönskär, the Grovstanäs massif, parish of Länna, Stockholms län. | ⩽1 | ⩽1 | <1 | <5 |
| Allivalite, grey, medium-grained. GS. | S of Båtdragsträsket, do., do., do. | 2 | 60 | 120 | 70 |
| Peridotite[2], black, coarse to medium-grained. GS. | Träffsholmen, do., do., do. | 5 | 200 | 450 | 250 |
| Ultra-basic olivine-gabbro, peridotitic, grey black, medium-grained. GS. | Ruggsättra, parish of Österåker, Stockholms län. | 5 | 90 | 250 | 100 |
| Lherzolite, black, coarse to medium-grained. GS. | Near Fastarby, parish of Össeby-Garn, Stockholms län. | 6 | 75 | 250 | 100 |
| Ultra-basic uralite-gabbro, grey green, coarse to medium-grained. GS. | WNW of Vreta, the Rådmansö massif, parish of Rådmansö, Stockholms län. | 4 | 50 | 45 | 25—<br>—30 |
| Do., grey green black, medium-grained. GS. | Near Lagboda, parish of Länna, Stockholms län. | 2 | 50 | 31 | 80 |
| Ultra-basic diallage-gabbro, femic, black, fine-grained. GS. | NE of Nabbo, the Rådmansö massif, parish of Rådmansö, Stockholms län. | 3 | 90 | 32 | 350 |
| Ultra-basic norite, grey black, fine-grained. GS. | Lönsudden, the Grovstanäs massif, parish of Länna, Stockholms län. | 2 | 65 | 20 | 250 |
| Allivalite, black and pale grey, coarse, porphyritic (anorthite eyes). GS. | Åkerö, the Rådmansö massif, parish of Rådmansö, Stockholms län. | 100 | 60 | 80 | 160 |
| Do., diallage-bearing, black and grey, medium-grained. GS. | Near Fastarby, parish of Össeby-Garn, Stockholms län. | 60 | 80 | 120 | 40 |
| Ultra-basic uralite-gabbro, dark grey green, medium-grained. GS. | Beateberg, parish of Rö, Stockholms län. | 55 | 80 | 120 | 75 |
| Do., do., do. GS. | Rumsättra, parish of Riala, Stockholms län. | 100 | 60 | 75 | 50 |
| Davainite[3], black green, medium-grained. GS. | Hornsholmen, the Grovstanäs massif, parish of Länna, Stockholms län. | 220 | 75 | 170 | 230 |
| Ultra-basic diallage-gabbro, grey black, fine medium-grained. GS. | Near the roadway N of Sandasjön, parish of Rö, Stockholms län. | 85 | 190 | 65 | 45 |
| Ultra-basic norite, grey black, fine medium-grained. GS. | N of Sundby, parish of Östra Ryd, Stockholms län. | 50 | 65 | 115 | 65 |
| Ultra-basic uralite-gabbro, grey black, medium-grained. GS. | Quarry 3.5 km SSW of Norrtälje, parish of Frötuna, Stockholms län. | 55 | 55 | 27 | 140 |

II. Gotho-Karelian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Allivalite, black grey, medium-grained. GS. | 400 m WSW of Dennicketorp, the Eriksberg massif, parish of Filipstad, Värmlands län. | 3 | 65 | 95 | 80 |
| Ultra-basic olivine-gabbro, greenish grey black, medium-grained. GS. | 550 m W of Dennicketorp, do., do., do. | 100 | 70 | 110 | 100 |

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[1] The plagioclase contains 88 % An.

[2] Serpentinized, uralitized.

[3] Apophysis of meta-lherzolite from minor mass of ultra-basic gabbro.

**Table 8. Post-Svecofennian, pre-Algonkian, massive basites and associated granites[0] (for analyses of basic dike rocks and volcanics, see Table 9), in very approximate order of relative age.**

I. Svionian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Uralite-gabbro, quartz-bearing, greenish grey black. LS. | Islet 1 km N of Stora Bälgsnäs, parish of Hedesunda, Gävleborgs län. | 1 | 15 | 100 | 150 |
| Do., dioritic, green grey black. LS. | 800 m N—NNW of Stora Bälgsnäs, do., do. | 25 | 20 | 90 | 45 |
| Basic diorite, uralitic, greenish grey black. GS. | Do., do., do. | 200 | 30 | 160 | 100 |
| Diorite[1], greenish grey black. GS. | West margin, easternmost basite mass S of Stor-Illingen, parish of Stora Tuna, Kopparbergs län. | 150 | 35 | 200 | 70 |
| Quartz-monzonite, red black grey. LS. | 2 km ESE of Hyttön, parish of Älvkarleby, Uppsala län. | 5 | 23 | 50 | 120 |
| Hornblende-granite, quartz-syenitic, red grey. LS. | S of Nybo, parish of Tierp, Uppsala län. | 4 | 5 | 70 | 120 |
| Gneiss-granite, grey red, femic, porphyritic (pink microcline eyes[2]). LS. | 1700 m ESE of Hyttön, parish of Älvkarleby, Uppsala län. | 3 | 3 | 35 | 150 |
| Do., do., do., do. LS. | Near Tallåsbacken, S of Fäbodviken, parish of Söderfors, Uppsala län. | 1 | 2 | 35 | 100 |

II. Gotho-Karelian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Olivine-gabbro, dark grey. GS. | Notträsk ENE of Boden, parish of Över-Luleå, Norrbottens län. | 500 | 45 | 220 | 80 |
| Uralite-porphyrite, green black. GS. | 300 m NNE of Lindås, parish of Onsala, Hallands län. | 150 | 65 | 110 | 250 |
| Uralite-gabbro, green black grey to green grey black. GS. | 150 m NW of Rörvik, do., do. | 50 | 60 | 100 | 120 |
| Do., green black grey. GS. | 1600 m SW of the railway halt, Spärringe, parish of Västerlösa, Östergötlands län. | 50 | 50 | 100 | 120 |
| Norite, grey black. GS. | Between Smedsbygget and Halsbråten, W of Stavsjö, parish of Krokek, Östergötlands län. | 100 | 50 | 90 | 150 |
| Do., do. GS. | 200 m NE of Normstorp, parish of Slaka, Östergötlands län. | 150 | 30 | 100 | 55 |
| Uralite-norite, grey green black to green black. LS. | Do., do., do. | 50 | 20 | 80 | 50 |
| Uralitic gabbro, grey black. GS. | 400 m NE of Ingarp, parish of Nävelsjö, Jönköpings län. | 20 | 18 | 55 | 75 |
| Basic diorite, dark grey, in part greenish. LS. | Do., do., do. | 5 | 17 | 55 | 60 |
| Gabbro grading into norite, grey black. GS. | NW—NE of Ingarp, do., do. | 10 | 16 | 20 | 100 |
| Norite, grey black. LS. | 400 m N of Ingarp, do., do. | 2 | 23 | 17 | 200 |
| Uralite-porphyrite, grey black green. GS. | Road-cutting 900 m NNE—NE of Mörlunda church, parish of Mörlunda, Kalmar län. | ⩽1 | 26 | 45 | 200 |

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[0] Fine- to medium-grained rocks; the uralite and microcline eyes of the porphyritic varieties coarse.

[1] In part grading into pyroxenite and olivine-gabbro.

[2] Most frequently accompanied by grey plagioclase eyes of a somewhat smaller size.

### Table 9. Post-Svecofennian, basic dike rocks and volcanics,[0] in approximate order of relative age.

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Svionian uralite-porphyrite (coarse eyes), grey black green. GS. | 1 km ENE of Penningby, parish of Länna, Stockholms län. | 130 | 60 | 180 | 240 |
| Svionian meta-andesite, dark grey, porphyritic (small uralite eyes). GS. | WNW part of Solö, do., do. | 60 | 110 | 60 | 200 |
| Do., black grey. LS. | 4.5 km SSW of Norrtälje, parish of Frötuna, Stockholms län, | 45 | 90 | 90 | 230 |
| Do., dark grey. GS. | 3 km N of Penningby, do., do, | 5 | 80 | 22 | 250 |
| Svionian amphibolite (meta-basalt), black. GS. | Quarry in the NE suburbs of Norrtälje, Stockholms län. | ⩽1 | 42 | 2 | 60 |
| Do., do. LS. | 1 km NW of Penningby, parish of Länna, Stockholms län. | 1 | 45 | ⩽1 | 80 |
| Do., do. GS. | 800 m E of Hysingsvik, do., do. | 0 | 40 | ⩽1 | 200 |
| Do., do. GS. | 1.5 km ENE of Mellingeholm, parish of Frötuna, Stockholms län. | 0 | 40 | ⩽1 | 230 |
| Early Gotho-Karelian (?) metabasite[1], green black. GS. | 900 m W of Alkarp, SSW of Spärringe, parish of Västerlösa, Östergötlands län. | 0 | 50 | 20 | 400 |
| Gotho-Karelian amphibolite (Koster diabase), black. GS. | N and W parts of Nordkoster, parish of Tjärnö, Göteborgs and Bohus län. | 10 | 50 | 90 | 300 |
| Do., do. GS. | NE part of Sydkoster, do., do. | 5 | 45 | 85 | 250 |
| Gotho-Karelian uralite-diabase, green black. GS. | 300 m WSW of Skurebo, parish of Nye, Jönköpings län. | 25 | 23 | 85 | 160 |
| Gotho-Karelian hyperite, grey black. GS. | Baskarp, parish of Gustav Adolf, Skaraborgs län. | 2 | 50 | 50 | 60 |
| Sub-Jotnian(?) diabase, grey black. LS. | 1 km ESE of Norsborg, parish of Botkyrka, Stockholms län. | 80 | 23 | 120 | 100 |
| Jotnian(?) diabase, grey black. LS. | SW of Drevviken, parish of Huddinge, Stockholms län. | 70 | 20 | 110 | 75 |
| Jotnian olivine-dolerite, grey black. GS. | W part of the Breven dike, parish of Svennevad, Örebro län. | 10 | 70 | 125 | 55 |
| Jotnian(?) uralite-diabase, green black. LS. | Valöarna, parish of Värmdö, Stockholms län. | 10 | 65 | 65 | 60 |
| Jotnian olivine-diabase (Åsby diabase), green black grey. GS. | 900 m N of Stora Fjällingstjärn, parish of Norberg, Västmanlands län. | 5 | 40 | 65 | 60 |
| Do., do. GS. | Åsbyn, parish of Malung, Kopparbergs län. | <1 | 55 | 60 | 70 |
| Jotnian diabase, amygdaloid, black (Gävle diabase). GS. | Parish of Valbo, Gävleborgs län. | 2 | 65 | 55 | 120 |
| Palaeozoic plateau-diabase (Västgöta diabase), grey black. GS. | Halleberg, Hunneberg, Mösseberg and Ålleberg, Älvsborgs and Skaraborgs län. | 6 | 400 | 200 | 230 |
| Palaeozoic plateau-diabase, grey black. GS. | Mount Peljekajse, parish of Arjeplog, Norrbottens län. | 5 | 50 | 80 | 200 |
| Tertiary basalt, black. GS. | Sösdala, parish of Norra Mellby, Kristianstads län. | 23 | 35 | 120 | 100 |
| Do., do. GS. | Anneklev, parish of Höör, Malmöhus län. | 25 | 30 | 100 | 100 |

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[0] Medium- to fine-grained rocks (most frequently fine-grained).

[1] Mainly composed of penninite, epidote, ore and apatite. Possibly early Svionian (*cf*. Table 5).

**Table 10. Single varves of Glacial clay and silt (Swedish mjäla).**

Geochronological analyses and geological determinations by E. FROMM (first number = age according to G. DE GEER, second number = thickness).

| Locality | Varve[1] | | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|---|
| Mestaängen, Mesta, parish of Folkärna, Kopparbergs län. | —705, 17 mm | summer | 5 | 20 | 25 | 150 |
| | | winter | 20 | 50 | 75 | 400 |
| 300 m NW of Lars Olsbo, parish of Västerfärnebo, Västmanlands län. | —742, 22 mm | summer | 5 | 15 | 25 | 500[6] |
| | | winter | 25 | 25 | 60 | 2500[6] |
| The railway station, Hedemora, Kopparbergs län. | —654 ± 20[2], 100 mm | summer | 6 | 8 | 15 | 100 |
| | | winter | 9 | 20 | 50 | 350 |
| Landsbro, Lake Hyen, parish of Stora Skedvi, Kopparbergs län. | —511 to 516, 6 mm[3] | summer | 6 | 15 | 40 | 250 |
| | | winter | 7 | 25 | 70 | 300 |
| Vallsta, parish of Stora Tuna, Kopparbergs län. | —541, 11 mm[4] | summer | 2—3 | 25 | 20 | 400 |
| | | winter | 4 | 40 | 45 | 500 |
| Gråda, parish of Gagnef, Kopparbergs län. | —449, 23 mm[5] | summer | c. 1 | 15 | 15 | 200 |
| | | winter | 3 | 25 | 45 | 350 |

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[1] Nothing else stated, the thickness given corresponds to the average of the adjacent varves.

[2] Approximate determination.

[3] Average thickness of the six varves analysed.

[4] Average thickness of ten adjacent varves = 9 mm.

[5] The adjacent varves show very variable thicknesses. The varve analysed belongs to the upper part of the range of variation obtained.

[6] These samples seem to have been contaminated by the zinc box containing the varve series.

**Table 11. Low- and non-metamorphic clay sediments (for analyses of single varves of Glacial clay, see Table 10).**

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Early Svionian clay slate, dark green grey. GS. | Skogen quarry, Grythyttehed, parish of Grythyttan, Örebro län. | 5 | 30 | 60 | 200 |
| Do., green grey. GS. | Hällefors, parish of Hällefors, Örebro län. | 6 | 25 | 60 | 200 |
| Gotho-Karelian(?) chlorite schist[1], dark greenish grey. LS. | 1 km WSW—SW of Målsön, parish of Kalix, Norrbottens län. | 5 | 80 | 110 | 400 |
| Gotho-Karelian clay slate, grey. GS. | Dalsland, Älvsborgs län. | 3 | 25 | 45 | 250 |
| Cambrian clay shale (*Ölandicus* shale), grey. GS. | Borgholm, Öland, Kalmar län. | 8 | 15 | 25 | 150 |
| Ordovician clay shale (*Tretaspis* shale), grey. GS. | Skogastorp, parish of Högstena, Skaraborgs län. | 20 | 60 | 150 | 200 |
| Tertiary (Eocene) clay, grey. GS. | Åhus, parish of Åhus, Kristianstads län. | 10 | 20 | 50 | 200 |
| Quaternary clay, grey, nonlayered, covered by 4 m moraine. GS. | Near Blåns, Grängesberg, parish of Grangärde, Kopparbergs län. | 5 | 25 | 55 | 300 |
| Glacial clay, brownish grey. GS[2]. | Åtorp, Medevi, parish of Västra Ny, Östergötlands län. | 5 | 15 | 35 | 250 |
| Do., reddish grey. GS[2]. | Lerbrotorp, parish of Nysund, Örebro län. | 5 | 25 | 25 | 250 |
| Do., do. GS[2]. | Norra Julön, do., do. | 6 | 20 | 30 | 250 |
| Glacial clay, brownish grey. GS[2]. | Bromma, Stockholm. | 5 | 20 | 60 | 230 |
| Do., grey. GS[2]. | Uppsala, Uppsala län. | 6 | 30 | 55 | 200 |
| Do., do. LS composed of 7 consecutive varves[3] (summer + winter). | S end of Stormyren NNE of Gysinge, parish of Hedesunda, Gävleborgs län. | 5 | 15 | 60 | 400 |
| Do., do. LS composed of 8 consecutive varves[3] (summer + winter). | Close to Gisselbäcken, 1.5 km NW of Gysinge, parish of Hedesunda, Gävleborgs län. | 3 | 18 | 55 | 350 |
| Ancylus clay, blue grey, covered by Litorina sand and gravels. LS. | 2250 m ENE of Kubbo, SE of Gävle, parish of Valbo, Gävleborgs län. | 5 | 25 | 60 | 170 |

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[1] Contaminated by traces of sulphide ore (chalkopyrite, pyrite, pyrrhotite).

[2] Composed of various summer and winter varves.

[3] Middle varves of the series.

**Table 12. High-metamorphic derivatives[0] of early Svionian and Gotho-Karelian(?) clay and silt.**

I. Svionian

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Leptite[1], dark grey, sometimes garnet-bearing[2]. GS. | NE end of Lillön near Vällinge, parish of Eckerö, Stockholms län. | 15 | 25 | 55 | 200 |
| Do., black grey, as a rule garnet-free. GS. | Centre of Lillön near Vällinge, do., do. | 10 | 25 | 50 | 150 |
| Veined gneiss[3], grey, garnet-bearing. LS.[2] | SE of Furängen W of Långbro, parish of Brännkyrka, Stockholm. | 6 | 30 | 50 | 200 |
| Do.[3], grey. LS. | Segeltorp, parish of Huddinge, Stockholms län. | 7 | 35 | 60 | 350 |
| Do.[3], do., garnet-bearing[2]. GS. | Road-cutting N of the railway station, Drevviken, do., do. | 4 | 50 | 80 | 200 |
| Do.[3], do., do[2]. GS. | Road-cutting close to the railway station, do., do., do. | 15 | 25 | 70 | 250 |
| Do.[3], do., do[2]. GS. | Road-cutting near Norrby, S of the railway station of Drevviken, parish of Österhaninge, Stockholms län. | 6 | 30 | 50 | 250 |
| Veined gneiss, grey red. LS. | Skogsö at Baggensfjärden N of Saltsjöbaden, Stockholms län. | 8 | 10 | 40 | 150 |
| Veined gneiss[3], grey, garnet-bearing[2]. GS. | Road-cutting 6 km NE of Vagnhärad, parish of Hölö, Södermanlands län. | 5 | 20 | 50 | 250 |
| Do.[3], red grey. GS. | Road-cutting NE of Lagmansö, parish of Vadsbro, Södermanlands län. | 30 | 45 | 90 | 140 |
| Do.[3], do. GS. | Road-cutting in Speteby, parish of Lerbo, Södermanlands län. | 10 | 25 | 40 | 300 |
| Do.[3], do. GS. | Road-cutting S of Arvidstorp, parish of Näshulta, Södermanlands län. | 20 | 20 | 40 | 200 |
| Mica schist, grey, layered, rather low in alumina[4]. LS. | Islet in Stora Norn N of Skedvibacken, parish of Hedemora, Kopparbergs län. | 2 | 20 | 30 | 100 |
| Veined gneiss[4], grey, with layers of leptite. GS. | The Caroline hospital, Solna, Stockholms län. | 3 | 10 | 20 | 120 |
| Leptite gneiss[4], dark grey, layers in veined gneiss. LS. | 800 m NE of the railway station, Rotebro, parish of Sollentuna, Stockholms län. | 5 | 20 | 50 | 250 |

II. Gotho-Karelian(?)

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Mica schist, black grey, pyrrhotite-bearing. LS. | E of Hamntjärn, ENE of Jävre, parish of Hortlax, Norrbottens län. | 10 | 15 | 45 | 200 |
| Biotite gneiss, dark grey. LS. | 600 m NE of Orrmyrtjärn, SSW of Jävre, do., do. | 8 | 30 | 100 | 50 |

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[0] Fine- to medium-grained rocks, the veined gneisses in part coarse.

[1] Inclusions in veined gneiss.

[2] Red violet garnet.

[3] Contains cordierite, sillimanite, sometimes andalusite, too.

[4] No special alumina minerals observed (silt derivative belonging to the Larsbo series = Uppermost early Svionian, or 'Bottnian').

**Table 13. Impure clay sediments (incl. high-metamorphic derivatives).**

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Early Svionian slate, black, graphite-bearing. GS. | Stentryås W of Grythyttehed, parish of Grythyttan, Örebro län. | 6 | <2 | 10 | 400 |
| Early Svionian veined gneiss, red grey, high in graphite. GS. | 800 m W of Fjällskäfte, parish of Floda, Södermanlands län. | 15 | 15 | 35 | <50 |
| Gotho-Karelian(?) slate, black, graphite- and pyrite-bearing.[1] GS. | Hastaskäret, the Kalix Skerries, parish of Nederkalix, Norrbottens län. | 10 | 50 | 180 | 300 |
| Cambrian shale (*Tessini* shale), greenish grey, sandy. LS. | Borgholm, Öland, Kalmar län. | 1 | 2 | 3 | 1000 |
| Cambrian alum shale (*Paradoxides-Tessini* shale), black. GS. | Byklev, Hunneberg, parish of Västra Tunhem, Älvsborgs län. | 15 | 30 | 70 | 200 |
| Ordovician alum shale (*Dictyonema* shale), black. GS. | Ottenby, parish of Ås, Öland, Kalmar län. | 30 | <2 | 25 | 400 |
| Post-Glacial clay, grey, cultivated (field clay). GS. | Bränninge near Södertälje, parish of Tveta, Stockholms län. | 3 | 6 | 12 | 150 |
| Do., do., do. GS. | Österhaninge, parish of Österhaninge, Stockholms län. | 3 | 5 | 15 | 130 |
| Do., do., do. GS. | Svartsjö, parish of Sånga, Stockholms län. | 4 | 5 | 15 | 80 |
| Do., do., do. GS. | Blidö, parish of Blidö, Stockholms län. | 5 | 3 | 15 | 180 |
| Do., do., do. GS. | Rimbo, parish of Rimbo, Stockholms län. | 5 | ≦2 | 5 | 150 |
| Do., do., do. GS. | Ultuna, Uppsala, Uppsala län. | 4 | ≦2 | 8 | 230 |
| Do., do., do. GS. | Harg, parish of Harg, Stockholms län. | 10 | 5 | 8 | 220 |
| Do., do., do. GS. | Örbyhus, parish of Vendel, Uppsala län. | 30 | 4 | 40 | 170 |

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[1] In part rather high in graphite.

**Table 14. Metasomatic and leached derivatives of clays and silts.**

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Svionian veined gneiss, grey, medium-grained, granitized. GS. | Road-cutting 600 m W of Svalbo, parish of Näshulta, Södermanlands län. | 20 | 10 | 20 | <50 |
| Triassic clay (Rät-Lias), grey to grey violet. GS. | Bjuv, parish of Bjuv, and Billesholm, parish of Södra Vram, Malmöhus län. | 6 | 25 | 8 | 180 |
| Cretaceous clay, pale grey to reddish grey. GS. | Åsen, W of Axeltorpsviken (Ivösjön), parish of Näsum, Kristianstads län. | 1 | 20 | 7 | 170 |

**Table 15. Various low- and non-metamorphic sediments (for analyses of clay sediments, see Tables 10—11 and 13).**

| Character | Locality | Cr | Co | Ni | Zn |
|---|---|---|---|---|---|
| Gotho-Karelian(?) slate[1] composed of sericite and quartz, violet. LS. | Salto, parish of Jokkmokk, Norrbottens län. | 2—3 | <1 | <2 | <30 |
| Cambrian quartz-sandstone, yellowish (*Fucoid* sandstone). GS. | Kinnekulle, Skaraborgs län. | ≤1 | 1 | 2 | <5 |
| Do., red and yellowish. GS. | Kalmarsund, Kalmar län. | <1 | <2 | ≤2 | ≤5 |
| Ordovician limestone, grey. GS. | Lovene, parish of Karleby, Skaraborgs län. | 5 | 2 | 10 | ≤50 |
| Do., do. GS. | Skövde, Skaraborgs län. | 5 | 1 | 3 | ≤50 |
| Do., red. GS. | Våmb, parish of Våmb, Skaraborgs län. | 4 | <1 | 7 | ≤50 |
| Do., do. GS. | Hällekis, parish of Österplana, Skaraborgs län. | 4 | 1 | 3 | ≤50 |
| Do., grey. GS. | Grönhögen, parish of Ventlinge, Öland, Kalmar län. | 5 | <1 | 2 | ≤50 |
| Do., red. GS. | Gräsgård, parish of Gräsgård, Öland, Kalmar län. | 25 | 7 | 90 | — |
| Post-Glacial quartz sand[2], pale grey. GS. | Karlholmsbruk, parish of Västland, Uppsala län. | 5 | ≤2 | 5 | ≤30 |
| Post-Glacial sand, meagre[3], greyish, cultivated. GS. | Skärplinge, parish of Österlövsta, Uppsala län. | 6 | 3 | 30 | 170 |

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[1] Sedimentary *in-situ*-derivative of quartz-porphyry (see Table 4).

[2] Contaminated with organic compounds.

[3] Very fine-grained sand, corresponding to Swedish '*mo*'.

Table 16. Distribution of chromium in the rocks and soils analysed.

| Character | n | 0—2 | 3—9 | 10—24 | 25—49 | 50—99 | 100—199 | ≥200 |
|---|---|---|---|---|---|---|---|---|
| Leptites, leptite gneisses, gneisses (Table 1) | 22 | **10** | **10** | 2 | | | | |
| Svecofennian granites. I. Main fraction (Table 2) | 25 | **10** | 9 | 5 | 1 | | | |
| Do. II. Late varieties (Table 2) | 9 | **7** | 2 | | | | | |
| Younger Archaean granites (Table 3) | 18 | **15** | 3 | | | | | |
| Porphyries, rhyolites (Table 4) | 6 | **5** | 1 | | | | | |
| Early Svionian, basic volcanics (Table 5) | 13 | **9** | 3 | 1 | | | | |
| Svecofennian basites (Table 6) | 24 | 2 | 2 | 4 | 2 | 3 | 3 | **8** |
| Younger Archaean ultra-basites (Table 7) | 19 | 4 | **6** | | | 5 | 3 | 1 |
| Younger Archaean, massive basites (Table 8) | 20 | 4 | 4 | 2 | 1 | 3 | 4 | 2 |
| Post-Svecofennian, basic dike rocks and volcanics (Table 9) | 24 | **8** | 5 | 4 | 3 | 3 | 1 | |
| Single varves of Glacial clay and silt (Table 10) | 12 | 1 | **9** | 1 | 1 | | | |
| Low- and non-metamorphic clay sediments (Table 11) | 16 | | **14** | 2 | | | | |
| High-metamorphic Archaean clay and silt (Table 12) | 17 | 1 | **9** | 6 | 1 | | | |
| Impure clay sediments (Table 13) | 14 | 1 | **7** | 4 | 2 | | | |
| Metasomatic and leached clays (Table 14) | 3 | 1 | 1 | 1 | | | | |
| Various other sediments (Table 15) | 11 | 2 | **8** | | 1 | | | |

**Table 17. Distribution of cobalt in the rocks and soils analysed.**

| Character | n | 0—2 | 3—9 | 10—24 | 25—49 | 50—99 | 100—199 | ≥200 |
|---|---|---|---|---|---|---|---|---|
| Leptites, leptite gneisses, gneisses (Table 1) | 22 | **10** | 6 | 5 | 1 | | | |
| Svecofennian granites. I. Main fraction (Table 2) | 25 | 4 | 8 | **9** | 4 | | | |
| Do. II. Late varieties (Table 2) | 9 | **9** | | | | | | |
| Younger Archaean granites (Table 3) | 18 | **17** | 1 | | | | | |
| Porphyries, rhyolites (Table 4) | 6 | **6** | | | | | | |
| Early Svionian, basic volcanics (Table 5) | 13 | | | **6** | 4 | 3 | | |
| Svecofennian basites (Table 6) | 24 | | | 3 | **14** | 7 | | |
| Younger Archaean ultra-basites (Table 7) | 19 | 1 | | | | **16** | 1 | 1 |
| Younger Archaean, massive basites (Table 8) | 20 | 1 | 2 | **8** | 5 | 4 | | |
| Post-Svecofennian, basic dike rocks and volcanics (Table 9) | 24 | | | 3 | 8 | **11** | 1 | 1 |
| Single varves of Glacial clay and silt (Table 10) | 12 | | 1 | **5** | **5** | 1 | | |
| Low- and non-metamorphic clay sediments (Table 11) | 16 | | | **7** | **7** | 2 | | |
| High-metamorphic Archaean clay and silt (Table 12) | 17 | | | 7 | **9** | 1 | | |
| Impure clay sediments (Table 13) | 14 | 5 | 6 | 1 | 1 | 1 | | |
| Metasomatic and leached clays (Table 14) | 3 | | | **2** | 1 | | | |
| Various other sediments (Table 15) | 11 | **9** | 2 | | | | | |

Table 18. Distribution of nickel in the rocks and soils analysed.

| Character | n | 0—2 | 3—9 | 10—24 | 25—49 | 50—99 | 100—199 | ≥200 |
|---|---|---|---|---|---|---|---|---|
| Leptites, leptite gneisses, gneisses (Table 1) | 22 | **11** | 3 | 2 | 4 | 1 | 1 | |
| Svecofennian granites. I. Main fraction (Table 2) | 25 | 6 | **11** | 6 | 2 | | | |
| Do. II. Late varieties (Table 2) | 9 | **9** | | | | | | |
| Younger Archaean granites (Table 3) | 18 | **16** | 1 | 1 | | | | |
| Porphyries, rhyolites (Table 4) | 6 | **5** | | | | 1 | | |
| Early Svionian, basic volcanics (Table 5) | 13 | 3 | 1 | **6** | 2 | 1 | | |
| Svecofennian basites (Table 6) | 24 | 1 | | 2 | 4 | 6 | **8** | 3 |
| Younger Archaean ultra-basites (Table 7) | 19 | 1 | | 1 | 4 | 4 | **6** | 3 |
| Younger Archaean, massive basites (Table 8) | 20 | | | 2 | 3 | **7** | 6 | 2 |
| Post-Svecofennian, basic dike rocks and volcanics (Table 9) | 24 | 4 | | 2 | | **11** | 6 | 1 |
| Single varves of Glacial clay and silt (Table 10) | 12 | | | 3 | **5** | 4 | | |
| Low- and non-metamorphic clay sediments (Table 11) | 16 | | | | 5 | **9** | 2 | |
| High-metamorphic Archaean clay and silt (Table 12) | 17 | | | 1 | 5 | **10** | 1 | |
| Impure clay sediments (Table 13) | 14 | | 4 | **5** | 3 | 1 | 1 | |
| Metasomatic and leached clays (Table 14) | 3 | | **2** | 1 | | | | |
| Various other sediments (Table 15) | 11 | **4** | **4** | 1 | 1 | 1 | | |

**Table 19. Distribution of zinc in the rocks and soils analysed.**

| Character | n | 0—≤50 | 50—85 | 90—145 | 150—215 | 220—295 | 300—395 | ≥400 |
|---|---|---|---|---|---|---|---|---|
| Leptites, leptite gneisses, gneisses (Table 1) | 22 | **11** | 3 | 2 | 5 |  | 1 |  |
| Svecofennian granites. I. Main fraction (Table 2) | 25 | 1 | 2 | 6 | **12** | 3 | 1 |  |
| Do. II. Late varieties (Table 2) | 9 | **6** | 1 |  | 2 |  |  |  |
| Younger Archaean granites (Table 3) | 18 | **8** | 4 | 2 | 4 |  |  |  |
| Porphyries, rhyolites (Table 4) | 6 | 2 |  |  | **4** |  |  |  |
| Early Svionian, basic volcanics (Table 5) | 13 | 1 | 2 | 1 | **4** | 3 | 1 | 1 |
| Svecofennian basites (Table 6) | 24 | 5 | **10** | 7 | 1 | 1 |  |  |
| Younger Archaean ultra-basites (Table 7) | 19 | 4 | **6** | 4 | 1 | 3 | 1 |  |
| Younger Archaean, massive basites (Table 8) | 20 | 1 | 6 | **7** | 5 | 1 |  |  |
| Post-Svecofennian, basic dike rocks and volcanics (Table 9) | 24 |  | **8** | 4 | 4 | 6 | 1 | 1 |
| Single varves of Glacial clay and silt (Table 10) | 12 |  |  | 1 | 2 | 1 | 3 | **5** |
| Low- and non-metamorphic clay sediments (Table 11) | 16 |  |  |  | **7** | 5 | 2 | 2 |
| High-metamorphic Archaean clay and silt (Table 12) | 17 |  | 1 | 3 | **7** | 4 | 2 |  |
| Impure clay sediments (Table 13) | 14 | 1 | 1 | 1 | **5** | 2 | 1 | 3 |
| Metasomatic and leached clays (Table 14) | 3 | 1 |  |  | **2** |  |  |  |
| Various other sediments (Table 15) | 10 | **9** |  |  | 1 |  |  |  |

**Table 20. Distribution of chromium, cobalt, nickel and zinc in the rocks and soils analysed (for comparison, some other analyses are also considered).**

| Character | n | Cr $\geq$ 25. Co, Ni and Zn variable | (Co + Ni) $\geq$ 50; Co $\geq$ 10, Ni $\geq$ 15. Cr and Zn variable | Zn $\geq$ 100. Cr, Co and Ni variable | Cr $\geq$ 10, Co $\geq$ 10, Ni $\geq$ 20. Zn variable | Cr > Ni > Co; Cr $\geq$ 25. Zn variable | Cr < Ni $\geq$ Co; Ni $\geq$ 20. Zn variable | Cr < Co $\geq$ Ni; Co $\geq$ 3. Zn $\geq$ 30 | Co $\geq$ (Cr + Ni); Co $\geq$ 3. Zn $\geq$ 30 | Co > Ni > Cr; Co $\geq$ 10. Zn $\geq$ 50 | Cr $\leq$ 5, Co $\geq$ 20, Ni $\leq$ 20, Zn $\geq$ 50 | Cr $\leq$ 5, Co $\leq$ 2, Ni $\leq$ 10. Zn variable | Ni $\geq$ 20, Zn $\geq$ 100. Cr and Co variable | Cr < Co $\leq$ Ni; Ni $\geq$ 15. Zn variable | Cr < Co < Ni < Zn; Zn $\geq$ 50 | Cr $\leq$ 10, Co = 10—50, Ni = 20—200, Zn = 50—500 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Leptites, leptite gneisses, gneisses (Table 1) | 22 | | 3 | 8 | | | 6 | 4* | 4 | 2 | | 8 | 3 | 5 | 2 | 2 |
| Svecofennian granites I. Main fraction (Table 2) | 25 | 1 | 3 | **22** | 3 | | 3 | **14** | 9 | 6 | 1 | 4 | 5 | 3 | 5 | 3 |
| Do. II. Late varieties (Table 2) | 9 | | | 2 | | | | | | | | **9** | | | | |
| Younger Archaean granites (Table 3) | 18 | | | 6 | | | | 1 | 1 | | | **17** | | | | |
| Porphyries, rhyolites (Table 4) | 6 | | | **4** | | | 1 | | | | | **5** | | | | |
| Early Svionian, basic volcanics (Table 5) | 13 | | 5 | **9** | 1 | | 2 | **12** | **10** | **11** | **9** | | 3 | 1 | | 4 |
| Svecofennian basites (Table 6) | 24 | **16** | **20** | 9 | **18** | **13** | 6 | 5 | 4 | 3 | 1 | | 9 | 4 | 2 | 5 |
| Younger Archaean, massive ultrabasites (Table 7) | 19 | 9 | **18** | 9 | 9 | 3 | 9 | 5 | 5 | 3 | 1 | 1 | 9 | 8 | | 1 |
| Younger Archaean, massive basites (Table 8) | 20 | **10** | **15** | **13** | **12** | 5 | **14** | 1 | 1 | 1 | 1 | | **12** | 8 | 8 | 5 |
| Post-Svecofennian, basic dike rocks and volcanics (Table 9) | 24 | 7 | **20** | **16** | 11 | | **15** | **12** | 8 | 6 | 5 | | **14** | 11 | 4 | 6 |
| Single varves of Glacial clay and silt (Table 10) | 12 | 1 | **7** | **12** | 2 | | **9** | 2 | 1 | 1 | 1 | | **10** | **10** | **9** | **8** |
| Low- and non-metamorphic clay sediments (Table 11) | 16 | | **15** | **16** | 2 | | **16** | 1 | | | | | **16** | **16** | **15** | **14** |
| High-metamorphic Archaean clay and silt (Table 12) | 17 | 1 | **16** | **16** | 7 | | **17** | | | | | | **16** | **16** | **15** | **13** |
| Impure clay sediments (Table 13) | 14 | 2 | 3 | **12** | 3 | 1 | 4 | | | | | 3 | 4 | 4 | 6 | 1 |
| Metasomatic and leached clays (Table 14) | 3 | | | **2** | 1 | | | **2** | **2** | **2** | 1 | | | | | |
| Various other sediments (Table 15) | 11 | 1 | | 1° | | | 2 | | | | | **9** | 1° | | | |
| Residual aplites and granophyres, Scotland and Greenland (Mitchell; pp. 13—14) | 4 | | | — | | | | | | | | **3** | | | | |
| Gotho-Karelian ophiolites, Northern Finland (Sahama; p. 12) | 7 | **7** | **7** | — | **7** | **6†** | | | | | | | | | | |
| Caledonian ophiolites, Northern Sweden (Du Rietz; p. 11) | 8 | **8** | — | — | — | — | | | | | | | | | | |
| Caledonian plutonic rocks**, Western Scotland (Mitchell; pp. 10—11) | 25 | **25** | **20** | — | **21** | **22** | | | | | | | | | | |
| Plutonic rocks††, the Skaergaard intrusion, Greenland (Mitchell, p. 10) | 8 | 3 | **4** | — | 3 | 2 | | **5‡** | **5‡** | — | 3‡ | | — | | | |
| Tyrrhenian sediments (Landergren; p. 15) | 16 | **9** | **14** | | **15** | 3 | 7 | 3‡ | 1‡ | | | | — | 3 | — | — |

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* 5, when a rock showing Zn $<$ 50 is included. — ° n = 10. — † or 7, *cf.* p. 12. — ** From the Garabal Hill—Glen Fyne complex (acid residuals excluded) and the Carn Chois intrusion. — †† Acid residuals excluded. — ‡ Zn not reckoned.

Fat figures mean $\geq$ 50 % of the number of samples of each group of rocks analysed.

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