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THE STUDY OF ACCESSORY MINERALS IN IGNEOUS AND METAMORPHIC ROCKS*

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INTRODUCTION

The constantly increasing interest of geologists during the last 25 years in the study of accessory minerals in igneous and metamorphic rocks, and in the distribution of these minerals in sediments led to the formation, in 1931, of a Committee on Accessory Minerals of Crystalline Rocks in the Division of Geology and Geography of the National Research Council. Much of the work in this general field has been done by British scientists, but in recent years, in part because of the application of results to oil-field problems, the work of others along this line has been stimulated.

Winchell,[1] in the first report of the committee, defined its field as "a study of the nature of the accessory minerals of crystalline rocks, their variation in time and space in igneous bodies and metamorphosed masses, and their distribution in sediments."

The present paper traces the development of the study of accessory minerals in igneous and metamorphic rocks, and of the application of such study to broader problems of igneous geology, such as correlation of, or differentiation between, igneous masses. The paper is based largely on the abstracts of the literature that have been prepared by the various members of the committee, as the first stage of the committee's work. The phase of the subject having to do with the distribution of the accessory minerals in sediments is not considered here.

DEFINITION OF ACCESSORY MINERAL

Any worker in the field of accessory minerals in igneous and metamorphic rocks soon discovers that the term "accessory mineral" has a variety of meanings, the meaning in any particular paper depending on the writer who is using it. When the study of these minerals is set aside as a particular field of activity, it is apparent that either there must be some unanimity of usage of the principal term involved, or else each writer must define his usage.

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[1] Winchell, A. N., and others, Accessory minerals of crystalline rocks: *Nat. Research Council, Bull.* **89**, p. 142, 1932.

According to Webster's dictionary,[2] "accessory" used as an adjective modifying things means "accompanying as a subordinate; aiding or contributing in a secondary way; connected as an incident or subordinate to a principal; additional," and "accessory mineral" is defined as "any mineral not regarded as an essential constituent of a particular rock, although it may be frequently, or even usually, present."

Holmes' similar definition[3] is "a term applied to minerals occurring in small quantities in a rock, whose presence or absence does not affect its diagnosis."

La Forge's definition[4] is practically identical, being "those mineral constituents of a rock that occur in such small amounts that they are disregarded in its classification and definition. Opposed to essential minerals."

Osann[5] divides the rock minerals into three main groups—the essential or major constituents (*Wesentlichegemengteile* or *Hauptgemengteile*), the minor constituents (*Nebengemengteile*), and the subordinate or excess constituents (*Akzessorischegemengteile* or *Übergemengteile*).

The *Nebengemengteile* include such minerals as apatite, iron ores, and zircon. They are present in most rocks but are not used in naming the rock and are not essential to the rock. The *Übergemengteile* are further subdivided into vicarious or substituted subordinate constituents (*vikariierende*), characteristic subordinate constituents (*charakteristischen*), and accidental or fortuitous subordinate constituents (*zufällige*). The first subgroup includes such minerals as tourmaline in place of mica in granite, or haüynite in place of nepheline in tephrite. The second embraces such minerals as titanite in granite, pyrope in serpentine, or perovskite in melilite basalt. Examples of the minerals of the third subgroup are fluorite in granite, galena in sandstone, and sphalerite in limestone.

Johannsen[6] classifies the mineral constituents of igneous rocks as follows:

"Primary—{ Essential or chief constituents
Accessory—{ Minor accessories
Auxiliary minerals

Secondary constituents—Caused by { Addition of material
Replacement
Weathering

[2] Webster's new international dictionary of the English language, 1931.

[3] Holmes, Arthur, *The nomenclature of petrology*, p. 23, London, Thos. Murby & Co., **1920.**

[4] Fay, A. H., A glossary of the mining and mineral industry: *U. S. Bur. Mines, Bull.* **95,** p. 13, 1920.

[5] Osann, A., *Elemente der Gesteinslehre*, H. Rosenbusch, pp. 17–18, Stuttgart, **1923.**

[6] Johannsen, Albert, *A descriptive petrography of the igneous rocks*, p. 28, Univ. Chicago Press, **1931.**

Included (foreign) constituents——{May be rock fragments or minerals}

"The primary constituents were formed during the solidification of the rock. Of these, the essentials are those which, by definition, are necessary to the rock. The accessory constituents embrace the minor accessories and the auxiliary minerals. The former include small amounts of the minerals usually present, such as apatite, zircon, titanite, the iron ores, etc., whose absence or presence does not change the classification of the specimen. In some cases the accessory minerals are of unusual interest or they have become so prominent that they are conspicuous—for example, titanite in syenite, or topaz or tourmaline in granite. Such minerals may be called auxiliary constituents. Secondary minerals may be introduced by the addition of material such as boron, fluorine, etc., to form tourmaline, topaz, fluorite, etc.; they may be formed by replacement, as kaolin, chlorite, epidote, amphibole, titanite, calcite, quartz, etc.; or by weathering, as calcite, limonite, and indeterminable hydrous aluminum silicates."

Wright,[7] in a paragraph on the classification and general features of accessories, notes the classifications used by Grantham and by Wells. Grantham[8] makes two divisions—primary or pyrogenic accessories, such as zircon, apatite, and fluorite; and secondary or infiltrated accessories, including such minerals as tourmaline, topaz, and some fluorite. Wells[9] classifies accessories of granites as normal (zircon, titanite, etc.), pneumatolytic (tourmaline, topaz), contamination (garnet, andalusite), and secondary (epidote, zoisite). One unfamiliar with the individual meanings given to terms would be confused to find that the "primary" accessories of one paper are the "normal" accessories of another, and that the "secondary" accessories of one author are pneumatolytic and of another hydrothermal.

Winchell,[10] as chairman of the Committee on Accessory Minerals of Crystalline Rocks, writes, "In the work of the committee and in research work related to it a serious question has arisen this year regarding the meaning of the term 'accessory minerals.' Five members of the committee are agreed in the following statements:

[7] Wright, J. F., Accessory minerals in the study of granite batholiths: *Roy. Soc. Canada Trans.*, 3d ser., vol. **26,** sec. 4, pp. 253–254, 1932.

[8] Grantham, D. R., The petrology of the Shap granite: *Geol. Assoc. Proc.*, vol. **39,** pp. 304–307, 1928.

[9] Wells, A. K., The heavy-mineral correlation of intrusive igneous rocks: *Geol. Mag.*, vol. **68,** pp. 255–262, June 1931.

[10] Winchell, A. N., Report of the committee on accessory minerals of crystalline rocks for 1934–35: *Nat. Research Council, Div. Geology and Geography*, Ann. Rept., **1935,** Appendix F, p. 1, April 27, 1935.

"For the purposes of the committee, the 'accessory minerals' of rocks are those which are present in such small amounts that they are studied to the best advantage by methods involving concentration rather than by ordinary thin-section methods. Such minerals as quartz and even feldspar are occasionally found in very small amounts in certain igneous rocks. Nevertheless, they are not considered as accessory minerals, even in those rocks, because there is at present no known advantage to be derived from studying them by concentration methods.

"Accessory minerals should not be confused with the 'heavy minerals'; hornblende and biotite are examples of heavy minerals which are rare in some granites and are therefore often included among the accessory minerals. But, at least in most cases, it seems to be true that they can be studied to the best advantage by ordinary thin-section methods. Furthermore, experience has shown that if they are included in the studies made by concentration methods, they are likely to introduce difficulties quite out of proportion to any benefits derived from their study by these methods.

"Professor Tolman does not agree with these statements but states that the term 'accessory minerals' has a quite definite meaning and any redefinition may cause confusion. He thinks the purpose might be achieved simply by pointing out the group of minerals most suitable for study through concentration. He agrees that the inclusion of the ferromagnesian minerals may obscure the more significant relations of the more useful minerals, and, moreover, that they are best studied in thin section."

The report does not state which "definite" meaning of the term "accessory minerals" is adhered to by Professor Tolman. Presumably it is the more general one, as expressed by the dictionary, Holmes, or La Forge, and not either of the more restricted meanings as used by Osann or Johannsen.

The present writer now feels that the general rather inclusive meaning as worded by Holmes, namely, "a term applied to minerals occurring in small quantities in a rock, whose presence or absence does not affect its diagnosis," is the best. The definition has two distinct advantages. First, it applies to all rocks—igneous, metamorphic, and sedimentary. Secondly, its meaning is almost inflexible. The simple definite qualifications must be met: an accessory mineral must be present in small amount and its presence or absence must not affect the diagnosis of the enclosing rock. The only latitude in application lies in the interpretation of what percentages of a mineral constitute "small quantities." Perhaps the definition could be worded "occurring in quantities so small that they do not affect the diagnosis of the rock."

This definition is, of course, very broad, as it includes minerals formed by recrystallization, by hydrothermal activity, by pneumatolysis, and even by weathering. Under this usage of the term the accessory minerals may then be appropriately subdivided as required for a more specific meaning. One convenient basis of subdivision is suggested by the first sentence of this paragraph—namely, that of genesis. Another might be based on physical properties—for example, "heavy accessories" could be those whose specific gravity is greater than 2.86, the specific gravity of bromoform. A third could be based on chemical composition, thus giving a group such as "sulphide accessories."

According to such a classification most of the literature on accessories in igneous and metamorphic rocks that has been abstracted and studied by the committee has dealt with "primary heavy accessories," "pneumatolytic heavy accessories," and "hydrothermal heavy accessories."

The Development of the Study of Accessory Minerals of Igneous and Metamorphic Rocks

Most of the early and many of the recent papers on igneous and metamorphic rocks either entirely ignore the accessories or simply mention the species identified. Occasionally they were given more attention, and the following citations from those papers published prior to that of Rastall and Wilcockson[11] in 1915 will serve to illustrate early attempts to use the accessories in the study of igneous and metamorphic rocks.

As early as 1884 Thurach[12] noted the widespread distribution of zircon, rutile, anatase, and brookite. He described the crystallography of anatase and brookite, and came to the conclusions that anatase and brookite never occur in unaltered crystalline rock but are first developed at the time of replacement, that anatase and brookite have been formed in the sedimentary rocks and are found also in secondary ore deposits, that the pseudobrookite found in altered basalt and phonolite of the Kreuzberg stock in the Rhone Valley was formed during the weathering of the basalt and phonolite, and that in considering the derivation of the sedimentary rocks from the various rocks of the basement complex, staurolite, of all the minerals found in the sedimentary rocks, deserves special consideration.

Rastall and Wilcockson[13] cite two early papers of Khrushchov,[14] who

[11] Rastall, R. H., and Wilcockson, W. H., The accessory minerals of the granitic rocks of the English Lake district: *Geol. Soc. London Quart. Jour.*, vol. **71,** pp. 592–622, 1915.

[12] Thurach, Hans, Über das Vorkommen mikroskopischer Zirkone und Titanmineralien in den Gesteinen: *Physikal. med. Gesell. Wurzburg Verh.*, neue Folge, *Band* **18,** Nr. 10, pp. 1–82, 1884.

[13] Rastall, R. H., and Wilcockson, W. H., *op. cit.*, pp. 618–619.

[14] Khrushchov, K. D., Über holocrystalline makrovariolithische Gesteine: *Acad. Imp. Sci. St.-Pétersbourg Mém.*, ser. 7, vol. **42,** no. 3, 1894; Beitrag zur Kenntnis der Zirkone in Gesteinen: *Min. Pet. Mitt.*, neue Folge, *Band* **12,** p. 423, 1886.

attempted to determine what habits of zircon are characteristic of various igneous and metamorphic rocks.

In 1893 Keyes[15] stated that the primary nature of epidote in Maryland granites is indicated by its presence in fresh rocks, its occurrence as inclusions in sphene, its good crystal outline, and the presence in it of cracks containing biotite in optic orientation with surrounding biotite crystals. Almost contemporaneously, Hobbs[16] came to the same conclusions on similar evidence.

Trueman,[17] in 1912, pointed out that zircon may not always be formed as a pyrogenetic igneous rock mineral but may originate or be secondarily enlarged through the agency of water or gases emanating from intrusions. Two years later Winchell[18] used the presence of well-rounded zircon particles in schists of the Rabbit district, Montana, as evidence that the schists are of sedimentary origin because "nearly all zircon in igneous rocks and their metamorphic equivalents is clear and sharply angular."

Leith and Mead[19] made a more general statement the next year, when they said; "The separation of minute accessory constituents by washing is a means for identifying origin of schists and gneisses which has not yet been sufficiently used. Minerals of igneous rocks, like monazite, zircon, sphene, and garnet, are remarkably resistant to weathering and remain in well-defined crystals in the residual mantle when all the other constituents have altered. When transported they become worn and rounded and tend to segregate with sand rather than argillaceous sediments. In the schistose equivalent of the sand deposits the rounded grains persist, particularly the zircons, and afford evidence of sedimentary origin."

Later work has shown that the zircons of many igneous rocks are well rounded by resorption. The work of Rastall and Wilcockson[20] on the rocks of the English Lake district was the most comprehensive study of the accessories of a suite of igneous rocks that had been attempted to 1915. This paper marked the beginning of a new phase of studies of this type. Their earlier studies of accessories of igneous rocks in connection

[15] Keyes, C. R., Epidote as a primary component of eruptive rocks: *Geol. Soc. Am. Bull.*, vol. **4**, pp. 305–312, 1893.

[16] Hobbs, W. H., New occurrence of parallel intergrowths of the minerals allanite and epidote: *Am. Geologist*, vol. **12**, pp. 218–219, 1893.

[17] Trueman, J. D., The value of certain criteria for the determination of the origin of foliated crystalline rocks: *Jour. Geology*, vol. **20**, p. 248, 1912.

[18] Winchell, A. N., Mining districts of the Dillon quadrangle, Montana, and adjacent areas: *U. S. Geol. Survey, Bull.* **574**, p. 128, 1914.

[19] Leith, C. K., and Mead, W. J., *Metamorphic geology*, p. 225, New York, Henry Holt & Co., **1915**.

[20] Rastall, R. H., and Wilcockson, W. H., *op cit.*, pp. 592–622.

with investigations of the origin of certain minerals in sediments led them to undertake the examination of a well-defined group of igneous rocks. The rocks of the Lake district were selected because material was available, the district includes several intrusive bodies that have variations within themselves and that have numerous apophyses with a considerable range in rock type, and the geologic relations and petrographic character of the rocks were well known.

These authors say: "The accessory minerals of the rocks examined show very wide variations. Nevertheless, when the results for each intrusion are taken separately, there is evidence of a distinct similarity running through all varieties. . . . On the whole, the rarer constituents of each intrusion show a fairly constant distribution, but this resemblance does not always extend to the apophyses. . . . The general results of this work, when compared with the published descriptions, show that enumerations of accessory minerals founded on the examination of rock sections alone are quite inadequate and often misleading. . . . The whole procedure is so simple and rapid that it might well be applied to all investigations of igneous rocks, as a check on the results obtained from rock sections alone."

The next stage in the development of studies of accessory minerals is marked by a group of papers by Brammal and Harwood,[21] who studied the petrology of the Dartmoor granite, with emphasis on the accessories. In their third paper cited here they use the term "index figure," which is defined as the average percentage by weight of mineral grains of specific gravity greater than 2.86 obtainable from crushed rock material that has been washed free from rock flour. This term has since come into more or less general usage.

Milner[22] points out the value of such work as that of Brammal and

[21] Brammal, Alfred, and Harwood, H. F., The occurrence of rutile, brookite, and anatase on Dartmoor: *Mineralog. Mag.*, vol. **20**, pp. 20–26, 1923; Occurrences of zircon in the Dartmoor granite: *Idem*, vol. **20**, pp. 27–31; The Dartmoor granite—its mineralogy, structure, and petrology: *Idem*, vol. **20**, pp. 39–53; The occurrence of a gold-bearing pegmatite on Dartmoor: *Idem*, vol. **20**, pp. 201–211, 1924; Tourmalinization in the Dartmoor granite: *Idem*, vol. **20**, pp. 319–330, 1925.

Brammal, Alfred, The Dartmoor granite: *Geol. Assoc. London Proc.*, vol. **37**, pp. 251–277, 1926; Gold and silver in the Dartmoor granite: *Mineralog. Mag.*, vol. **21**, pp. 14–20, 1926.

Brammal, Alfred, and Harwood, H. F., The temperature range of formation for tourmaline, rutile, brookite, and anatase in the Dartmoor granite: *Mineralog. Mag.*, vol. **21**, pp. 205–220, 1927.

Brammal, Alfred, Dartmoor detritals—A study in provenance: *Geol. Assoc. London Proc.*, vol. **39**, pp. 27–48, 1928.

[22] Milner, H. B., *Sedimentary petrography*, pp. 408, 409, London, Thomas Murby & Co., **1929.**

Harwood: "The work on the Dartmoor granite has yielded abundant evidence of the value attaching to an intensive study of such accessory minerals. It has shown the existence of a rich and varied collection of species, many of which were previously not known to occur in that rock; it has stressed and proved conclusively the significance of varietal characters of these minerals and has thus been the direct means of focusing attention on mineral vagaries so often passed by as adventitious or unimportant. The wider investigations, combining both field and laboratory observations, have shown that particular accessory mineral assemblages may be characteristic of certain stages of intrusion or consolidation, or of specific developments and modifications of the normal rock, thus materially aiding correlation or differentiation of types. Their potentiality extends also to geochemical data, with which petrogenic problems are intimately bound up. Thus has a new scope of inquiry been instituted, a comprehensive technique established, which neither igneous nor sedimentary petrologists can afford to ignore."

In 1927 Groves[23] published the first two of several papers that deal principally with the study of the accessories of intrusive igneous rocks. He concludes that correlation of isolated plutonic outcrops by means of the accessories is very satisfactory for the whole area of the Channel Islands and that it demands further recognition. He says that it is quicker than chemical analysis and has the advantage that the crystallization history is also revealed. He points out that zircon and apatite are perhaps the minerals whose characters are likely to be the most useful for correlation and stresses the importance of varietal characters and "index figure."

Groves in his paper on the correlations of the granites of Brittany, the Channel Islands, and the Cotentin holds that, at least in these examples, neighboring granites, particularly masses injected along a com-

[23] Groves, A. W., The heavy minerals of the plutonic rocks of the Channel Islands—1, Jersey: *Geol. Mag.*, vol. **64,** pp. 241–251, 1927; The heavy minerals of the plutonic rocks of the Channel Islands—2, Guernsey, Sark, and Alderney: *Idem*, pp. 457–473; The identification of dumortierite as grains; dumortierite in Cornish granites: *Mineralog. Mag.*, vol. **21,** pp. 489–492, 1928.

Groves, A. W., and Mourant, A. E., Inclusions in the apatites of some igneous rocks: *Mineralog, Mag.*, vol. **22,** pp. 92–99, 1929.

Groves, A. W., The heavy mineral suites and correlations of the granites of northern Brittany, the Channel Islands, and the Cotentin: *Geol. Mag.*, vol. **67,** pp. 218–240, 1930; The heavy mineral suites of the Uganda granites: *Uganda Geol. Survey, Ann. Rept.*, **1929,** pp. 40–41, 1930; The unroofing of the Dartmoor granite and the distribution of its detritus in the sediments of southern England: *Geol. Soc. London Quart. Jour.*, vol. **87,** pp. 62–96, 1931; The heavy mineral suites and correlation of the Uganda granites: *Uganda Geol. Survey, Ann. Rept.*, **1930,** pp. 38–39, 1931; Appendix I to the geology of southwest Ankole: *Geol. Survey Uganda, Memoir* **11,** pp. 196–213, 1932.

mon tectonic axis, reflect their relationships in possessing heavy mineral suites with many points in common, and this because such minerals as zircon, apatite, monazite, rutile, iron ores, and sphene generally crystallize from the magma at an early stage of the cooling and thus, in their color, inclusions, habits, and peculiarities, exhibit marked characteristics dependent on the original composition and early cooling history.

Wells[24] in 1931 severely criticized the methods and conclusions of Groves. He shows that over a period of three years Groves reversed himself on the age that he would assign to the Channel Island granites. Wells says: "Comparing rocks of the same petrographic type, of the same genetic history, and occurring in comparable situations in relation to the contemporaneous fold axes, we shall expect identity of mineral composition if, and only if, the rock bodies have had the same cooling history—in other words, if they are alike in size, manner of injection, thickness of roof, etc."

He states that the pneumatolytic accessories will be most abundant in the higher parts of an intrusion and that ultimately they will be completely removed by erosion. "Therefore, . . . , the minerals of this class are without value as indicators of age."

Contamination accessories, to Wells' mind, are completely lacking in time significance. The value of "secondary accessories," by which Wells means such paulopost or deuteric minerals (minerals produced during the later stages as a direct consequence of the consolidation of the magma of the rock) as members of the chlorite, serpentine, and epidote groups, for correlation is minimized.

Wells next takes up certain "normal accessories" (those developed independently of any special controlling factors such as high flux content) and one by one eliminates them from the group that he considers of possible value for the uses claimed for accessory-mineral studies. Finally he states that zircon and possibly some other minerals, at least in theory, might be unique in certain rocks and therefore of value.

In conclusion Wells says: "Only in so far as the cooling history of an intrusion has been unique can one reasonably expect the rocks to yield a distinctive heavy-mineral suite: only in as much as the cooling history of two or more intrusions has been alike can one expect similarity in heavy-mineral content. To use heavy minerals for correlation is to claim both the uniqueness of the first, and the similarity of the second supposition. It is asking much, and in the writer's opinion, is not proven."

Groves[25] answers Wells' contentions by pointing out that the reason he

[24] Wells, A. K., The heavy-mineral correlation of intrusive igneous rocks: *Geol. Mag.*, vol. **68**, pp. 255–262, 1931.

[25] Groves, A. W., The heavy-mineral correlation of igneous rocks: *Geol. Mag.*, vol. **68**, pp. 526–527, 1931.

assigns different ages to some of the same granites in the Channel Islands in different papers is that certain stratigraphic links have changed at the hands of other workers, owing in part to his work with the heavy minerals.

He says that it is to be expected that "normal accessories" would be less affected by the size of the intrusion, manner of injection, thickness of the roof, etc., than the major constituents, because these minerals normally crystallize before disturbing influences can act on them.

He points out that even the pneumatolytic minerals have some correlation value. In their almost complete lack of beryllium minerals, the Armorican granites of Devon and Cornwall, Channel Islands, Normandy and Brittany contrast strongly with the Tertiary granites of the Mourne Mountains.

In summation he says that several writers have amply proved that generic features distinguish Armorican granites from pre-Cambrian, Caledonian, and Tertiary masses, while at the same time more specialized characters permit distinction between the heavy mineral assemblages of single intrusions.

Other British contributors to the accessory mineral studies of igneous and metamorphic rocks during the period 1923 to 1932 include Chatterjee,[26] Ghosh,[27] Grantham,[28] Leech,[29] Mackie,[30] and Smithson.[31] All these writers place more or less confidence in the use of studies of accessory minerals in the correlation or differentiation of igneous and metamorphic masses and in problems of provenance.

[26] Chatterjee, M., The accessory mineral assemblage of the Bodmin Moor granite (Cornwall): *Geol. Assoc. London Proc.*, vol. **40,** pp. 147–152, 1929.

[27] Ghosh, P. K. Petrology of the Bodmin Moor granite (eastern part), Cornwall: *Mineralog, Mag.*, vol. **21,** pp. 285–309, 1927; The mineral assemblage of the Falmouth granite (Cornwall): *Geol. Assoc. London Proc.*, vol. **39,** pp. 332–338, 1928.

[28] Grantham, D. R., The petrology of the Shap granite: *Geol. Assoc. London Proc.*, vol. **39,** pp. 299–331, 1928.

[29] Leech, J. G. C., St. Austell detritals: *Geol. Assoc. London Proc.*, vol. **40,** pp. 139–146, 1929.

[30] Mackie, William, The principles that regulate the distribution of particles of heavy minerals in sedimentary rocks, as is illustrated by the sandstones of the northeast of Scotland: *Edinburgh Geol. Soc. Trans.*, vol. **11,** pp. 138–164, 1923; The source of the purple zircons in the sedimentary rocks of Scotland: *Idem*, pp. 200–213; Dumortierite in British rocks: *Idem*, p. 352, 1925; The heavier accessory minerals in the granites of Scotland: *Idem*, vol. **12,** pp. 22–40, 1928; The heavy minerals in the Torridon sandstone and metamorphic rocks of Scotland and their bearing on the relative ages of these rocks: *Idem*, pp. 181–182.

[31] Smithson, Frank, Geological studies in the Dublin district—I, The heavy minerals of the granite and the contiguous rocks in the Ballycorus district: *Geol. Mag.*, vol. **65,** pp. 12–25, 1928; The petrography of the northern portion of the Leinster granite: *Idem*, vol. **69,** pp. 465–474, 1932.

Each year since the formation of the National Research Council Committee on Accessory Minerals, in 1931, Winchell has summarized the work along this line done or in progress in North America. Much of it has been the work of graduate students at various universities under the direction of professors who were particularly interested in problems relating to accessory minerals. Several papers[32] have appeared, and more are to be expected in the near future.

Occasionally an investigator comes to a conclusion such as that reached by Jenks, who states that the heavy accessories are of little value to the petrographer. Marsden, however, shows that Jenks' data tend to support and not to disqualify the principles of work on heavy minerals.

Most of the recent workers with accessory minerals recognize that such studies are still in their infancy. Nearly all are willing to grant the soundness of some of the basic principles involved. Most recognize the value for correlation, differentiation, and other purposes of studies of accessory minerals under favorable conditions, even in the present rudimentary state of our knowledge. In general, the North American workers in this field show a tendency to advance cautiously, taking full cognizance of the

[32] Reed, J. C., and Gilluly, James, Heavy-mineral assemblages of some of the plutonic rocks of eastern Oregon: *Am. Mineral.*, vol. **17**, no. 6, June 1932.

Wright, J. F., Accessory minerals in the study of granite batholiths: *Royal Soc. Canada Trans.*, 3d ser., vol. **26**, sec. 4, pp. 251–265, 1932.

Singewald, Q. D., Alteration as an end phase of igneous intrusion in sills on Loveland Mountain, Park County, Colo.: *Jour. Geology*, vol. **40**, pp. 16–20, 1932.

Boos, M. F., and Boos, C. M., Granites of the Front Range: The Longs Peak-St. Vrain batholith: *Geol. Soc. Am. Bull.*, vol. **44**, pp. 72–73, 1933.

Lamey, Carl A., The intrusive relations of the Republic granite: *Jour. Geology*, vol. **41**, pp. 487–500, 1933.

Boos, M. F., Granites of the Front Range—The heavy minerals (abstract): *Geol. Soc. Am. Proc.*, 1933, p. 67, **1934.**

Boos, M. F., and Boos, C. M., Granites of the Front Range: The Longs Peak-St. Vrain batholith: *Geol. Soc. Am. Bull.*, vol. **45**, pp. 303–322, 1934.

Jenks, W. F., Heavy minerals in the syenite of Pleasant Mountain, Maine: *Am. Mineral.*, vol. **19**, pp. 476–479, 1934.

Stark, J. T., Heavy minerals in the Tertiary intrusives of central Colorado: *Am. Mineral.*, vol. **19**, pp. 586–592, 1934.

Marsden, Ralph W., Discussion of the paper "Heavy minerals in the syenites of Pleasant Mountain, Maine": *Am. Mineral.*, vol. **20**, pp. 132–135, 1935.

Taylor, G. L., Pre-Cambrian granites of the Black Hills: *Am. Jour. Sci.*, 5th ser., vol. **29**, pp. 278–291, 1935.

Tolman, Carl, and Koch, H. L., Accessory mineral suites in the granites of Missouri (abstract): *Am. Mineral.*, vol. **20**, p. 208, 1935.

Stark, J. T., and Barnes, F. F., The correlation of pre-Cambrian granites by means of heavy mineral analyses: *Geol. Mag.*, vol. **72**, no. 854, pp. 341–350, August 1935.

Newhouse, W. H., Opaque oxides and sulphides in common igneous rocks: *Geol. Soc. Am. Bull.*, vol. **47**, pp. 1–52, 1936.

difficulties and limitation of such studies. For example, Wright[33] says, "The accessories of igneous masses from many areas and of different ages, however, need to be studied in great detail before further broad and general conclusions can be presented regarding their usefulness in correlating and delimiting granite batholiths. The results of the investigations completed to date assuredly are encouraging enough to warrant a much more extended study of the accessories in granites than hitherto has been undertaken."

[33] Wright, J. F., *op. cit.*, p. 264.