THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERIÇA

Vol. 18 FEBRUARY, 1933 No. 2

ORIGIN AND CLASSIFICATION OF PEGMATITES[1]

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INTRODUCTION

HISTORY AND DEFINITION OF "PEGMATITE." The word "pegmatite" was coined originally by Haüy in the early years of the 19th century as a descriptive term applied to rocks with a graphic texture. According to Kemp[2] the word means "bound or cemented together in a framework." In 1849 "pegmatite" was used by Delesse[3] to designate a very coarse granite and gradually the use of the term was extended to include all types of exceptionally

[1] Awarded the second prize in the Walker Natural History Prize competition, May, 1932.

[2] Kemp, J. F., The pegmatites: *Econ. Geol.*, **19**, p. 699, 1924.

[3] Williams, G. H., Origin of the Maryland pegmatites: *U. S. Geol. Survey, 15th Ann. Rept.*, p. 675, **1895**.

coarse plutonic rocks whether graphic or not. Bastin[4] has stated that the distinguishing feature of pegmatites is not coarseness but irregularity of grain. Although irregularity of grain size is undoubtedly a feature of pegmatites, all of the pegmatites observed by the writer contained some relatively large mineral grains. The writer defines pegmatite as *an intrusive holocrystalline rock composed essentially of rock-making minerals which are developed in part in individuals larger than the grains of the same minerals occurring in the normal plutonic equivalent.* Minerals not classified as rock-forming may also be present in coarse crystals. In rare cases, notably the cryolite pegmatite of southwest Greenland, the essential components are not rock-forming minerals and exception must be made to the definition.

Shape and Size of Pegmatites. Pegmatites exhibit such a variety of shapes that it is impossible to choose any one as characteristic. Many are tabular (similar to dikes and veins) with one fairly definite dimension. They may be horizontal, vertical, or between the two extremes in inclination. Other pegmatites are circular or elliptical in plan ("pipes") with the axis vertical or nearly so. In places these bodies are funnel shaped, as is the Etta pegmatite in the Black Hills. Still other pegmatites have the shape described by Adams and Barlow[5] as "splashes" and by Lehmann as "flammen." Aside from the shapes mentioned there are a host of pegmatites of such irregularity that no descriptive word can be applied to them. However, the writer has observed that most of the pegmatites which have been exploited for feldspar, mica, cassiterite or other commercial minerals are either tabular bodies with very moderate dip or vertical masses with circular or elliptical cross-section.

Thin tabular bodies of pegmatite conformable to the structure of an enclosing layered rock, such as a gneiss, are known as lit-par-lit injections. The amount of injected material may be so great that the original rock has become subordinate.[6] Although the tendency of such injections is to parallel the banding of the pre-

[4] Bastin, Edson S., Geology of the pegmatites and associated rocks of Maine, including feldspar, quartz, mica and gem deposits: *U. S. Geol. Survey, Bull.* **445**, p. 10, 1911.

[5] Adams, Frank D., and Barlow, Alfred E., Geology of the Haliburton and Bancroft areas, Province of Ontario: *Can. Geol. Survey, Memoir* No. **6**, p. 140, 1910.

[6] Keith, Arthur, Gaffney-Kings Mt. Folio, South and North Carolina: *U. S. Geol. Survey, Geol. Folio* **222**, p. 6, 1931.

existing rocks, transverse offshoots are commonly present also. Gevers and Frommurze[7] examined 1,710 pegmatites in the Erongo area of Southwest Africa and found that 79 per cent of these were parallel to the strike of the schist while the remainder were transverse. A very common feature of pegmatites that are intruded into banded rock is a pinch and swell structure. Some "swells" or lenses have maximum widths of over 50 feet, but pinch laterally to a few feet or even disappear altogether.

Complete dimensions of pegmatites are very difficult to obtain, not only on account of their irregularity but also because they are rarely exposed in over two directions. As a general rule, the two dimensions traceable on the outcrop of a tabular pegmatite are finite. The width or thickness of the body is determined by the position of the hanging and foot walls. The length (distance along the strike) may not be much greater than the thickness, the pegmatite having either abrupt or tapering ends. Adams and Barlow[8] in the Haliburton and Bancroft areas of Ontario have noted pegmatites over 250 feet wide. One has an area of 3½ square miles, and the longest pegmatite dike is 4 miles long. According to George,[9] pegmatite dikes in the Archean rocks of the Alma district, Park County, Colorado, measure four hundred feet and more in the narrowest direction. Maitland[10] has described pegmatites in the Wodgina district of Western Australia which "vary from mere threads to veins over 500 feet in width." But greater than any of these is "a massive fringe of pegmatite up to 700 yards in breadth" that is mentioned by Harker[11] as occurring on the eastern highlands of Scotland. However, as the third dimension is not known this figure may not represent thickness.

The concept of pegmatites extending down into the earth for great distances cannot be accepted, since mining operations have uncovered a definite bottom in a number of localities. The down-

[7] Gevers, T. W., and Frommurze, H. F., The tin-bearing pegmatites of the Erongo area, South-West Africa: *Trans. Geol. Soc. S. Africa*, **32** (for 1929), pp. 111–149, 1930. (Abs. *Min. Abstr.*, **4**, pp. 411–412; Annot. Bibliog. *Econ. Geology*, **3**, p. 424).

[8] Adams, Frank D., and Barlow, Alfred E., Geology of the Haliburton and Bancroft areas, Province of Ontario: *Can. Geol. Survey, Memoir* No. **6**, p. 141, 1910.

[9] George, R. D., Geology and ore deposits of the Alma district, Park County, Colorado: *Colo. Geol. Survey, Bull.* **3**, p. 46, 1912.

[10] Maitland, A. Gibb., Third report on the geological features and mineral resources of the Pilbara gold field: *West. Australia Geol. Survey, Bull.* **23**, p. 48, 1906.

[11] Harker, A., Natural history of igneous rocks, New York, p. 327, **1909**.

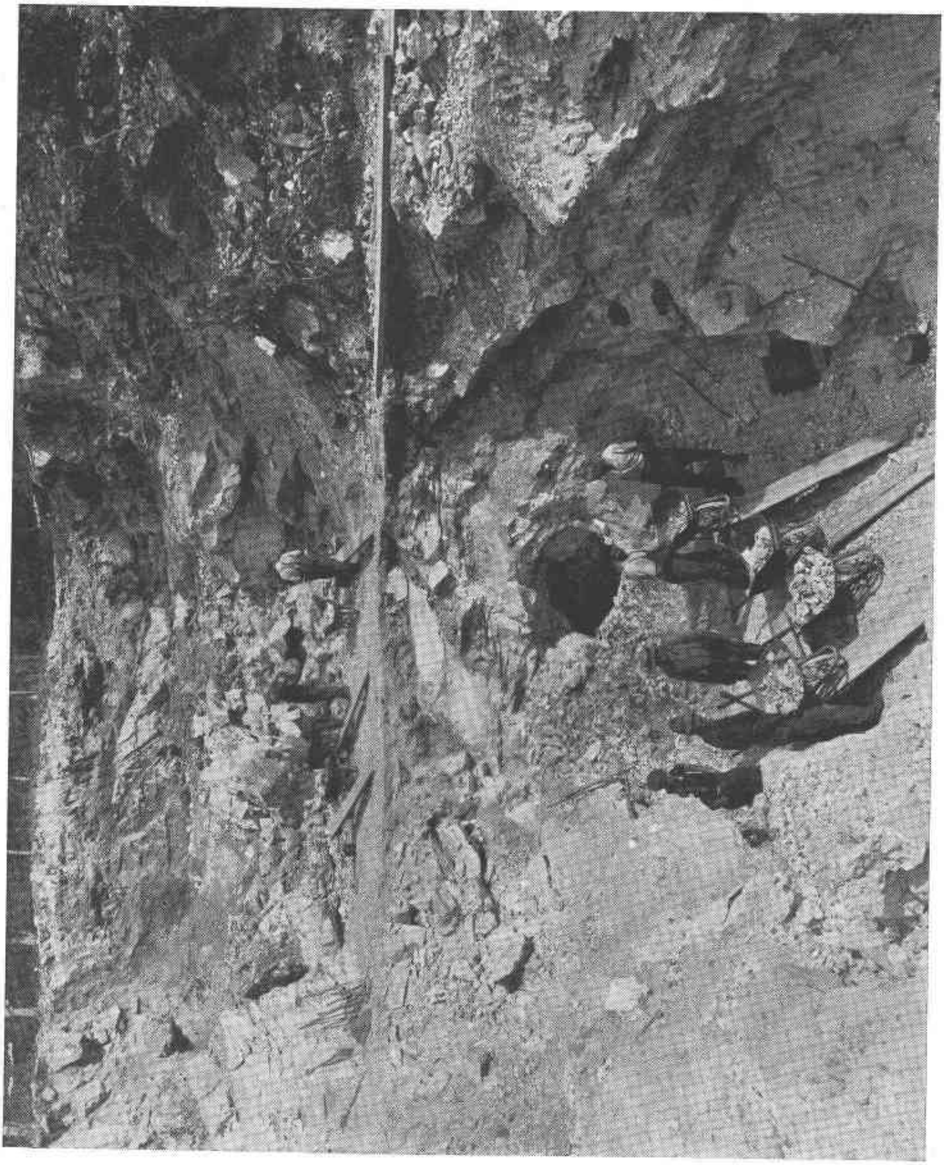

FIG. 1. Feldspar quarry, Buckfield, Maine, showing cavity uncovered during mining.

ward constriction of the Etta pegmatite has already been mentioned. Galpin[12] has noted in the Georgia pegmatites that although, due to the mountainous relief, it is possible to follow some pegmatites over a vertical range of several hundred feet, others pinch out within 20 or 30 feet. Similar observations have been

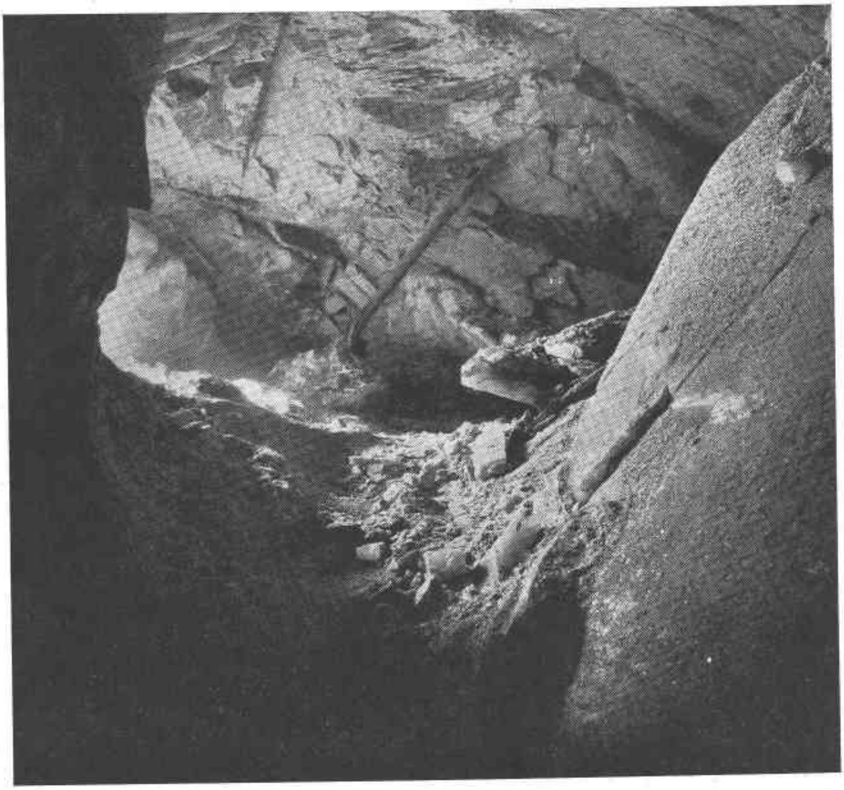

FIG. 2. View within pegmatite cavity, Buckfield, Maine.

made in the Amelia district in Virginia where a few pegmatites have been worked to a depth of 150 feet without reaching the bottom while others have played out entirely in 25 feet.[13] Keith[14]

[12] Galpin, S. L., A preliminary report on the feldspar and mica deposits of Georgia: *Georgia Geol. Survey, Bull.* **30,** p. 22, 1915.

[13] Pegau, A. A., The pegmatites of the Amelia, Goochland, and Ridgeway areas, Virginia: *Amer. Jour. of Sci.* (5), **17,** p. 543, 1929.

[14] Keith, Arthur, Gaffney-Kings Mt. Folio, South and North Carolina: *U. S. Geol. Survey, Geol. Folio* **222,** p. 12, 1931.

describes a pegmatite dike in the Carolinas as follows: "This pegmatite dike ranged from a thin seam to a mass six feet in thickness; it had a length of about 40 feet and extended to a depth of about 20 feet. The whole dike was removed in mining, leaving only a seam in the hypersthenite to show where it had pinched out to the west and in the bottom."

Cavities. Open spaces ranging in size from very minute cavities to large caves are a characteristic feature of many pegmatites (Figs. I and II). Large openings have been found in the pegmatites of Madagascar, central Maine, Llano County, Texas, and San Diego County, California. On the other hand, cavities are almost unknown in the large pegmatite bodies in the Black Hills. Pegmatite cavities are invariably lined with vuggy crystals, often of gem quality. Formerly such openings were considered to be caused by local segregations of water in the pegmatite magma which escaped subsequent to the consolidation of the pegmatite. Now, however, it is believed that these cavities are due to an excess of solution over precipitation on the part of hydrothermal waters of pegmatitic origin.[15]

Position with Respect to Parent Intrusions. Pegmatites are never found far from intrusive igneous rocks. Where a batholith is intruded into gneisses and schists, the adjacent country rock in most cases contains numerous pegmatite bodies. Those in Manitoba occur in roof pendants. Grout[16] in his studies of the Duluth gabbro has found pegmatites extending from the lower contact of the gabbro into the floor rock "to a distance equivalent to about 100 feet from the former position of the gabbro." Of greatest frequency is the occurrence of pegmatite in the laterally adjacent country rock. However, many pegmatite bodies occur entirely within what is probably the parent intrusive. In this case the contact between pegmatite and enclosing rock may be a gradational one.

Contact Metamorphic Effects. Although the thickness of the zone of contact metamorphism produced by a pegmatite is not comparable in magnitude to that produced by a batholithic intru-

[15] Landes, Kenneth K., The paragenesis of the granite pegmatites of central Maine: *Am. Mineralogist*, **10**, pp. 355–411, Nov. 1925. Hess, Frank L., The natural history of pegmatites: *Eng. & Mining Jour.-Press*, **120**, no. 8, pp. 289–298, Aug. 22, 1925. Palache, Charles, Davidson, S. C., and Goranson, E. A., The hiddenite deposit in Alexander County, North Carolina: *Am. Mineralogist*, **15**, pp. 280–302, 1930.

[16] Grout, F. F., The pegmatites of the Duluth gabbro: *Econ. Geol.*, **13**, p. 187, 1918.

sion, the suite of minerals produced is often a much more interesting one, for there is not only reaction between the pegmatite magma and the country rock, but in the case of the complex pegmatites (to be more fully described in the chapters on origin and classification) hydrothermal solutions of unusual character are produced which may wander out into the adjacent rock and create there a unique assemblage of minerals. Pegmatite metamorphism at the contact is not only exomorphic but also endomorphic, for in many localities wall rock contamination has produced abnormal mineralization within the border of the pegmatite. Fersman[17] classifies pegmatites into three types: (1) normal, (2) contact pegmatites, where there has been some exchange of material, and (3) migmatic pegmatites, where migration has been even more pronounced, especially in the removal of volatile constituents from the pegmatite magma.

As is to be expected, the greatest contact metamorphic effect takes place where pegmatitic magmas intrude limestone country rock. Nephelite-syenite pegmatites which have invaded limestone in Ontario contain sodalite, cancrinite, grossularite, nephelite, vesuvianite, and diopside in the contact zone.[18] The alkaline pegmatite of Magnet Cove, Arkansas, contains limestone inclusions in which mica, wollastonite, and thomsonite have formed.[19] Pegmatite dikes cutting limestone in Ferry County, Washington, have produced a garnet rock composed chiefly of andradite, albite and calcite within the limestone.[20] Newland[21] states that where pegmatitic invasions in the Adirondack area have reached limestone, contact metamorphic silicates and magnetite have been formed. Endomorphic action is well illustrated in Aberdeenshire, Scotland, where a coarse biotite pegmatite grades into a finer grained diopside-bearing rock where it traverses limestone bands. Diopside has also formed in the limestone. "There has thus been a reciprocal action, the pegmatite being enriched in lime and the limestone in

[17] Fersman, A. E., Über die migmatischen pegmatite des Urals. (Abs. *Min. Abstr.*, **3**, p. 84).

[18] Osborne, F. F., The nepheline-gneiss complex in Dungannon Township, Ontario, Canada: *Amer. Jour. of Sci.*, (5), **20**, p. 48, 1930.

[19] Landes, K. K., A paragenetic classification of the Magnet Cove minerals: *Am. Mineralogist*, **16**, p. 325, 1931.

[20] McLaughlin, D. H., Copper sulphides in syenite and pegmatite dikes: *Econ. Geol.*, **14**, p. 406, 1919.

[21] Newland, D. H., Structures in Adirondack magnetites: *Bull. Geol. Soc. Amer.*, **42**, p. 238, 1931.

silica."[22] Similar developments of diopside in pegmatite have been noted by Watson[23] in Howard County, Maryland, where a pegmatite magma is intruded along a dolomite-schist contact, and by Eskola[24] in western Massachusetts and Finland.

Neither have schists been immune to the metamorphosing action of intrusive pegmatites. Schwartz and Leonard[25] have noted that the schistosity of the country rock surrounding the Etta pegmatite in the Black Hills has been destroyed for a distance of 5 to 15 feet and the rock altered to one of grano-blastic texture. The contact minerals developed in this zone are feldspar, quartz, muscovite, tourmaline, apatite, zircon, and magnetite. Extensive tourmalinization of schist adjacent to pegmatite has been described in New Hampshire by Megathlin[26] and in Colorado by Patton.[27] Both garnet and tourmaline have been developed in the contact rocks in the Amelia area of Virginia.[28]

Although granite is much less susceptible to reaction and is less penetrable than limestone and schist, it also may contain an enrichment of unusual minerals adjacent to pegmatites. The cassiterite in the country rock surrounding the Zaiplaats tin pipes in the Bushveldt area of South Africa is an example. Also, the radial tourmaline groups in the Stone Mountain granite of Georgia described by Watson[29] probably were formed by solutions escaping from near-by pegmatites.

Of extreme interest to mineralogists is the contact metamorphism caused by the intrusion of pegmatites into the Franklin Furnace ore body which has been described by Ries and Bowen[30]

[22] Read, H. H., A diopside-bearing pegmatite near Ellon in Aberdeenshire: *Trans. Edinburgh Geol. Soc.*, **11**, pp. 353–356, 1925. (Abs. *Min. Abstr.*, **3**, p. 37).

[23] Watson, E. H., A diopside-bearing pegmatite in dolomite: *Econ. Geol.*, **24**, pp. 611–625, 1929.

[24] Eskola, Pentti, On contact phenomena between gneiss and limestone in western Massachusetts: *Jour. Geol.*, **30**, pp. 265–294, 1922.

[25] Schwartz, G. M., and Leonard, R. J., Contact action of pegmatite on schist: *Bull. Geol. Soc. Amer.*, **38**, No. 4, pp. 655–664, 1927.

[26] Megathlin, G. R., The pegmatite dikes of the Gilsum area, New Hampshire: *Econ. Geol.*, **24**, 2, pp. 163–181, 1929.

[27] Patton, H. B., Tourmaline and tourmaline schists from Belcher Hill, Colo.: *Bull. Geol. Soc. Amer.*, **10**, pp. 21–26, 1898.

[28] Pegau, A. A., The pegmatites of the Amelia, Goochland, and Ridgeway areas, Virginia: *Amer. Jour. Sci.*, (5), **17**, pp. 543–547, 1929.

[29] Watson, T. L., On the occurrence of aplite, pegmatite, and tourmaline bunches in the Stone Mountain granite of Georgia: *Jour. Geol.*, **10**, p. 193, 1902.

[30] Ries, H., and Bowen, W. C., Origin of the zinc ores of Sussex County, New Jersey: *Econ. Geol.*, **17**, pp. 517–571, 1922.

and Palache.[31] According to Palache the pegmatite contact minerals include most of those peculiar to that locality. They are divided into two groups (a) those that are due to mere recrystallization under abnormal temperatures or to direct reaction between the ores and silica and alumina of the pegmatite, and (b) those which are very evidently derived entirely from the pegmatite magma.

THEORIES OF ORIGIN

INTRODUCTION. The various theories which have been developed to account for the formation of pegmatites may be divided into two groups, aqueous and igneous. Included within the aqueous group are all of the theories in which near-by rocks rather than magmas are considered to be the source of the elements contained in the pegmatite minerals. Theories classified as igneous include all those in which the pegmatite minerals are considered to be of magmatic origin, either by direct crystallization, or by precipitation from hydrothermal solutions (attenuated magmas). Further subdivisions are made within each group.

The older theories of pegmatite origin have been reviewed in detail by a number of writers (Brögger,[32] Williams,[33] Crosby and Fuller,[34] Van Hise,[35] Spurr,[36] and Hastings[37]) between 1890 and 1908 so will be but briefly treated in this paper.

AQUEOUS THEORIES. The aqueous theories are divided into two groups, namely lateral secretion and selective solution. Lateral secretion, at one time very popular as applied to the genesis of ore veins, is now largely discarded for both ore veins and pegmatites. But the theory of selective solution still has many adherents when applied to the lit-par-lit pegmatites.

[31] Palache, Charles, Paragenetic classification of the minerals of Franklin, N. J.: *Am. Mineralogist*, **14**, pp. 1–18, Jan. 1929.

[32] Brögger, W. C., Die Mineralien der Syenitpegmatitgänge der Südnorwegischen Augit-und Nephelinsyenite: *Zeit. Kryst. Min.*, **16**, 1890.

[33] Williams, G. H., Origin of the Maryland pegmatites: *U. S. Geol. Survey, 15th Ann. Rept.*, pp. 675–684, **1895**.

[34] Crosby, W. O., and Fuller, M. L., Origin of pegmatites: *Am. Geol.*, **19**, pp. 147–180, 1897.

[35] Van Hise, C. R., Treatise on metamorphism: *U. S. Geol. Survey, Monograph* **47**, 1904.

[36] Spurr, J. E., Ore deposits of the Silver Peak Quadrangle, Nevada: *U. S. Geol. Survey, Prof. Paper* **55**, 1905.

[37] Hastings, John B., Origin of pegmatites: *Am. Inst. Mining Engineers Trans.*, **39**, pp. 105–128, 1909.

1. Lateral Secretion

According to the lateral secretion theory the source of the elements is the surrounding rock and ground water is the medium of solution, transportation, and reprecipitation. Saussure is credited by Crosby and Fuller[38] as the original proponent of this theory. It was most strongly supported in the United States by T. Sterry Hunt and at the time of Williams' paper (1895) was the prevailing theory. Williams[39] himself believed that both segregation (aqueous) and intrusive pegmatites were present in the Maryland areas which he studied. Van Hise[40] in 1904 attempted to add an aqueous modification to the igneous hypothesis: "As the pegmatites close to the central mass solidify a large portion of the water is expelled and travels outward to help form the pegmatitic rocks having a more distinctive vein character; but in many and perhaps most cases the water in the outlying pegmatite dikes and veins which more and more assume the character of ordinary veins has been largely derived from the surrounding rocks."

2. Selective Solution

The essence of the selective solution theory is that rock minerals in the presence of interstitial water may, with increase in pressure and temperature, go into solution and later reprecipitate to form a rock igneous in appearance and pegmatitic in texture. If the rock is a layered one, some layers may go into solution more readily than others. This would explain the alternation in the lit-par-lit pegmatities of what is apparently igneous rock with metamorphic rock. The basic principles of the theory of selective solution have been expressed by a number of geologists. For example, in Williams' review[41] he outlines the views of Kalkowsky and Goodchild as follows: "Kalkowsky suggests that pegmatite might be formed through the melting of granulite material brought about by dynamic agencies; and Goodchild has proposed that lenses of pegmatite might be due to local fusion through the relief of pressure

[38] Crosby, W. O., and Fuller, M. L., Origin of pegmatites: *Am. Geol.*, **19,** p. 162, 1897.

[39] Williams, G. H., Origin of the Maryland pegmatites: *U. S. Geol. Survey, 15th Ann. Rept.*, p. 679, **1895.**

[40] Van Hise, C. R., Treatise on metamorphism: *U. S. Geol. Survey, Monograph* **47,** p. 728, 1904.

[41] Williams, G. H., Origin of the Maryland pegmatites: *U. S. Geol. Survey, 15th Ann. Rept.*, p. 678, **1895.**

in rock masses which were potentially molten but kept in the solid state through pressure." In 1901 Julien[42] attributed the origin of pegmatites on Manhattan Island to molecular rearrangement of the material of the schist. Three years later Van Hise[43] described minute pegmatitic veins of quartz and feldspar in the Marquette district of Michigan. His monograph contains the following statement: "In this case it seems clear that pegmatization has taken place during the metamorphism of the rock in connection with mechanical action without the assistance of any extraneous igneous material, and is therefore essentially aqueous." Fenner[44] credits Sederholm with the belief that strata may become buried to sufficient depths as to become plastic in which case the more fusible portions will actually form a magma. The term "selective solution" was coined by Lane[45] in 1913 in a paper in which he states his belief that some of the Maine pegmatitic granites have this origin. Daly[46] is favorably impressed with this theory: "During intense regional metamorphism, especially that of the dynamic kind, deep-seated rocks charged with much interstitial water may reach the relatively low temperature at which minerals corresponding to the quartz-feldspar eutectic go into solution with the water and other volatile fluxes. Such small, locally generated pockets, lenses or tongues of fluid may be driven through the solid country rock for an indefinite distance; subsequently to crystallize with the composition and habit of the true batholithic derivatives. It is thus quite possible that these particular rocks, though truly magmatic, have had no direct connection with abyssal injections."

Although the theory of selective solution is a very plausible one for some of the lit-par-lit pegmatites, the writer is not convinced that it is a correct solution of the problem. According to field evidence there is every gradation between the thin inter-bed pegmatites and the large lenses which contain minerals with a chemical composition (i.e. beryl) which precludes origin from local materials.

IGNEOUS THEORIES. There are three igneous theories: (1) pegma-

[42] Julien, W. A., Notes on the origin of the pegmatites from Manhattan Island and from North Carolina: *N. Y. Acad. Sci. An.*, **13,** p. 507, 1901.

[43] Van Hise, C. R., Treatise on metamorphism: *U. S. Geol. Survey, Monograph* **47,** p. 725, 1904.

[44] Fenner, C. N., On the mode of formation of certain gneisses in the highlands of New Jersey: *Jour. Geol.,* **22,** p. 610, 1914.

[45] Lane, A. C., Origin of granites as well as metamorphic crystals by selective solutions: *Bull. Geol. Soc. Amer.*, **24,** p. 704, 1913.

[46] Daly, R. A., Igneous rocks and their origin, New York, p. 370, **1914**.

tites originate through crystallization of viscous magmas, (2) they originate through precipitation from highly attenuated magmas, and (3) the hydrothermal replacement theory, which is essentially a combination of the other two, involving two or more periods of formation ranging from magmatic to hydrothermal.

1. Viscous Magma Theory

The viscous magma theory is the "igneous theories" classification of Crosby and Fuller.[47] According to them, Charpentier was the first to clearly describe pegmatite origin through igneous agencies. He was followed by De la Beche, Bronn, Fournet, Durocher, Angelot, and Naumann. The viscous magma concept soon gave way to the aqueous magma theory, but it had an interesting revival in a paper by Merritt[48] in 1923 on the function of colloids in pegmatitic growths. Merritt describes the formation in gels of spherically radiating crystals, such as are often found in pegmatites, and also states his belief that the presence of the large spodumenes in the Etta pegmatite signifies high viscosity of magma. However, both the spherically radiating crystals and the large spodumene "logs" are much better explained, in the writer's opinion, by the third igneous theory, that of hydrothermal replacement.

2. Aqueous Magma Theory

The evolution of the aqueous magma or "aqueo-igneous" theory is well presented by Crosby and Fuller.[49] According to this theory, pegmatites are formed by precipitation from the attenuated residual magma resulting from the crystallization of a batholith. It was first advanced by Elie de Beaumont, and it found extremely strong support in the writings of Lehman and Crosby and Fuller. The greatest supporter of the aqueo-igneous theory in recent years was J. F. Kemp.[50]

3. Hydrothermal Replacement Theory

The hydrothermal replacement theory involves both magmatic crystallization and the precipitation, usually through replacement,

[47] Crosby, W. O., and Fuller, M. L., Origin of pegmatites: *Am. Geol.*, **19**, p. 163, 1897.

[48] Merritt, C. A., The function of colloids in pegmatitic growths: *Roy. Soc. Canada, Proc. and Trans.*, 3d ser., **17**, sec. 4, pp. 61–68, May, 1923.

[49] Crosby, W. O., and Fuller, M. L., Origin of pegmatites: *Am. Geol.*, **19**, p. 166, 1897.

[50] Kemp, J. F., The pegmatites: *Econ. Geol.*, **19**, p. 712, 1924.

of material in solution in waters of magmatic origin. There have been three stages in the evolution of this theory: (1) a period of development, (2) the culmination in 1925 with the publication of several papers containing important evidence, and (3) a subsequent period of verification during which additional evidence has been gathered by a number of investigators. These three periods will be taken up in chronological order.

Apparently Brögger[51] was the first to recognize the formation of pegmatites in successive stages. His classic on the southern Norway alkaline pegmatites was published in 1890, 35 years before the theory which he initiated became very widely accepted. However, during that interval a number of geologists and mineralogists recognized that the history of pegmatites was a complex one and expressed a belief in hydrothermal activity. Thus, Waring[52] who described the pegmatite veins of San Diego County, California, in 1905 states: "Later a more aqueous magma was forced up through the reopened crevices and formed the upper portions of the vein." Bayley[53] in 1910 published a report describing magnetite in the pegmatites of the New Jersey highlands in which occur the following sentences: "The magnetite is thus in two generations, the first of which crystallized before any of the other constituents of the rock and the second after all of the others had been formed. . . . The later magnetite, which is in the nature of a subsequent enrichment, was evidently introduced after the normal components of the rock had crystallized . . . Very probably the vehicle of transportation was a hot aqueous solution or possibly a vapor which emanated from the same magmatic source as the material that produced the pegmatite . . . The channels through which the solutions circulated presumably afforded the most favorable opportunities for deposition of mineral matter, and such portions of the rock naturally became richer in magnetite than other portions through which the solutions slowly percolated, and thus became the ore shoots. In some places there may have been replacement of the silicates by magnetite, causing further enrichment of the mass. . . ."

[51] Brögger, W. C., Die Mineralien der Syenitpegmatitgänge der südnorwegischen Augit-und Nephelinsyenite: *Zeit. Kryst. Min.*, **16,** 1890.

[52] Waring, G. A., The pegmatite veins of Pala, San Diego County, California: *Am. Geol.*, **35,** p. 366, 1905.

[53] Bayley, W. S., Iron mines and iron mining in New Jersey: *N. J. Survey Final Report*, **7,** pp. 150–151, 1910.

The possibility of a recurrence of pneumatolytic activity causing the development of cavities and the crystallization of aegirite and riebeckite in the pegmatites of Quincy, Mass., was mentioned by Warren and Palache[54] in 1911. In the same year Derby[55] described the mineralization of a gold-bearing lode of Passagem, Minas Geraes, Brazil, as occurring in three distinct processes. The first of these processes was the filling of a fissure with pegmatite. This was followed by fracturing and a second mineralization, which in Derby's opinion was possibly an after-effect of the granitic eruptions. The solutions active during the second stage precipitated tourmaline and sericitized the feldspar. During the third period of mineralization compounds of sulphur, arsenic, and the metals, including gold and silver, invaded the lode and probably also portions of the country rock.

Makinen[56] in 1913 described in considerable detail the pegmatites of Tammela, Finland, and the paragenesis of the pegmatite minerals. Two distinct periods of crystallization, one at temperatures above 575° C. and the second at lower temperatures, are recognized by Makinen. Brown tourmaline was formed during the earlier period and blue tourmaline during the later stage. There are similarly two generations of muscovite and quartz.

In two separate papers by Ziegler[57] published in 1914 a later phase of mineralization in the pegmatites of the southern Black Hills is mentioned. In one instance the replacement of pegmatite minerals by cassiterite is noted and the other paper describes deposition of amblygonite from solutions which rose through faulted and brecciated portions of the Peerless and Hugo pegmatites. In the same year Macdonald[58] described later cassiterite in the Bushveldt tin deposits in an article in which the following sentence appears: "The cassiterite is quite exceptionally found completely

[54] Warren, C. H., and Palache, Charles, The pegmatites of the riebeckite-aegirite granite of Quincy, Massachusetts, U. S. A.; their structure, minerals, and origin: *Am. Acad. Arts & Science Proc.*, **47**, p. 145, 1911.

[55] Derby, Orville A., On the mineralization of the gold-bearing lode of Passagem, Minas Geraes, Brazil: *Amer. Jour. Sci.*, 4th ser., **32**, pp. 185–190, 1911.

[56] Makinen, Eero, Die Granitpegmatite von Tammela in Finnland und ihre Minerale: *Commission Géologique de Finlande, Bull.* **35**, 1913, p. 22.

[57] Ziegler, Victor, The differentiation of a granitic magma as shown by the paragenesis of the minerals of the Harney Peak region, South Dakota: *Econ. Geol.*, **9**, pp. 264–277, April, 1914. The minerals of the Black Hills: *S. Dak. School of Mines, Bull.* **10**, 1914.

[58] Macdonald, D. P., Notes on the red feldspar of the Bushveldt tin deposits: *Trans. Geol. Soc. S. Africa*, **17**, p. 58, 1914.

within the valencianite, and in such cases it is evident that the mineral has been introduced along cracks, and probably part of the feldspar has been replaced."

Our modern concept of pegmatite crystallization was very well expressed by Galpin[59] in 1915: "After a pegmatite dike has partly or wholly formed, later magmatic solutions may come up along its walls through any cracks or openings which for various reasons may have developed in it. These solutions make a second deposit beside or in the first, resulting in a compound dike. In certain cases it seems that there are reactions between the later solutions and minerals in the pre-deposited rocks." The precipitation of a wide variety of hydrated phosphate minerals from hydrothermal solutions in the phosphate pegmatites of Bavaria was described by Laubmann and Steinmetz.[60]

McLaughlin[61] in 1919 published an account of dikes of syenite and syenite pegmatite containing chalcopyrite and bornite. In this paper the sulphides are considered to be a late product of the crystallization of the magma. They corrode the dike minerals. In his monograph on the mineralogy of Madagascar published in 1922, Lacroix[62] interprets the pegmatite cavities as products of corrosion in which were deposited later albite, tourmaline, and lepidolite.

In a paper published by J. H. L. Vogt[63] in 1926 reference is made to a lecture of Th. Vogt delivered a number of years earlier in which attention was called to the hydrothermal phase in granite pegmatites as follows: "To illustrate, there is the pure albite in druses deposited in crystallographic orientation of microcline and oligoclase; there is the muscovite in druses; there are the accompanying zeolites, etc."

Foye[64] in a paper on the pegmatites of the Middletown, Connecticut, area describes the recementation of fragments by tourmaline and apatite, which in his opinion took place through dep-

[59] Galpin, S. L., A preliminary report on the feldspar and mica deposits of Georgia: *Georgia Geol. Survey, Bull.* **30,** p. 27, 1915.

[60] Laubmann, H. und Steinmetz, H., Phosphatführende Pegmatite des Oberpfälzer und Bayerischen Waldes: *Zeit. Kryst. Min.*, **55,** p. 584, 1915–1920.

[61] McLaughlin, D. H., Copper sulphides in syenite and pegmatite dikes: *Econ. Geol.*, **14,** p. 409, 1919.

[62] Lacroix, Alfred, Mineralogie de Madagascar, *Paris,* p. 310, **1922.**

[63] Vogt, J. H. L., Magmas and igneous ore deposits: *Econ. Geol.*, **21,** p. 226, 1926.

[64] Foye, W. G., Mineral localities in the vicinity of Middletown, Connecticut: *Am. Mineralogist,* **7,** pp. 4–12, 1922.

osition by gases escaping from deep-seated sources. The concept of hydrothermal replacement was briefly suggested by Sterrett[65] in 1923 in the following words: "Some pegmatites were possibly formed in part by the intrusion of a magma and later modified by the passage of solutions from the same source." Penetration of earlier feldspars by "the end phase products, quartz and albite," is described in a paper published by Colony[66] during the same year.

But of outstanding importance during 1923 was the publication of two papers (written entirely in Russian) by A. E. Fersman.[67] In the first paper Fersman divides the mineralization of the nephelite-syenite pegmatites of the Kola peninsula into four phases: epimagmatic, pneumato-pegmatitic, pneumatolytic, and hydrothermal. He states: "The pneumatolytic phase is comparatively insignificant, especially when compared with the area in the vicinity of Christiania, while the hydrothermal phase is comparatively well developed and has an undoubted significance" (translated by M. K. Elias). In the second paper the origin of coronites (encrustation through substitution) is ascribed to "the action of the residual magma upon the previously crystallized minerals" (translated by M. K. Elias). A third paper published the following year[68] compares the pegmatite minerals associated with granitic magma at Mursinka, Urals, with those belonging to the nephelite-syenite intrusives of the Kola peninsula. Again the pegmatite mineralization is divisible into four phases, of which the last is hydrothermal.

The evolution of the hydrothermal replacement theory reached a peak in 1925 with the publication by five men, who worked entirely independently, of articles in which the paragenesis of pegmatite minerals is discussed in detail. Evidence is presented in each article to show that replacement is a dominant process, and the opinion is stated that hydrothermal solutions of magmatic origin are responsible for this later mineralization. The five investigators

[65] Sterrett, Douglas B., Mica deposits of the United States: *U. S. Geol. Survey Bull.* **740,** p. 10, 1923.

[66] Colony, R. J., The final consolidation phenomena in the crystallization of igneous rock: *Jour. Geol.*, **31,** p. 170, 1923.

[67] Fersman, A. E., Mineral associations in the Khibinsky and Lovozersky tundras: *Bull. Acad. Sci. Russie,* series 6, **1923,** pp. 65–80; Regular intergrowths of minerals in the Khibinsky and Lovozersky tundras: *loc. cit.*, pp. 275–290.

[68] Fersman, A. E., Ueber die Natur der Pegmatitbildungen: *Compt. Rend. Acad. Sci. Russie,* **1924,** pp. 89–92. (Abs. *Min. Abstr.*, **2,** p. 399).

are Cook,[69] Müllbauer,[70] Hess,[71] Schaller,[72] and Landes.[73] Cook, discussing a molybdenite deposit in an alaskite pegmatite in Nova Scotia, gives the sequence of magmatic activity starting with the intrusion of the granitic country rock and ending with the deposition of tourmaline, sericite, molybdenite, and bornite in vugs. Intermediate stages include (1) injection of a pegmatite magma, (2) mineralization by magmatic waters ("residuum of the original magma") between earlier aplite and pegmatite, between the quartz and orthoclase of the pegmatite, and along cleavage planes in the pegmatitic orthoclase, and (3) sericitization and deposition of molybdenite.

Müllbauer continued the work of Laubmann and Steinmetz[74] on the Bavarian phosphate pegmatites. The presence of more than one period of mineralization is emphasized in his paper. Two stages of a liquid magmatic phase were followed by a hydrothermal phase during which phospho-ferrite, lehnerite, apatite, columbite, muscovite in fine scaly masses, pyrite, sphalerite, and other minerals were deposited.

The paper by Hess on the natural history of pegmatites describes a number of instances in which replacement of one pegmatite mineral by another has taken place, drawing most of his illustrations from the pegmatites of the southern Black Hills. He also points out in vigorous fashion some of the inconsistencies in the older theories of pegmatite origin.

Schaller's paper is based on studies made by himself and E. S. Larsen of the pegmatites in the vicinity of Pala, California. He believes that graphic granite has been replaced by pegmatite minerals through hydrothermal activity. The principal evidence lies in finding "ghosts" of the graphic structure in the Pala pegmatites. The first stage in the replacement process was albitization which

[69] Cook, C. W., Molybdenite deposit near New Ross, Nova Scotia: *Econ. Geol.*, **20,** pp. 185–188, 1925.

[70] Müllbauer, F., Die Phosphatpegmatite von Hagendorf i. Bayern: *Zeits. Krist.*, **61,** pp. 318–336, 1925.

[71] Hess, Frank L., The natural history of pegmatites: *Eng. & Mining Jour.-Press*, **120,** no. 8, pp. 289–298, Aug. 22, 1925.

[72] Schaller, W. T., The genesis of lithium pegmatites: *Amer. Jour. Sci.*, **10,** pp. 269–279, Sept. 1925.

[73] Landes, Kenneth K., The paragenesis of the granite pegmatites of central Maine: *Am. Mineralogist*, **10,** pp. 355–411, Nov. 1925.

[74] Laubmann, H. und Steinmetz, H., Phosphatführende Pegmatite des Oberpfälzer und Bayerischen Waldes: *Zeit. Kryst. Min.*, **55,** p. 584, 1915–1920.

was accompanied or followed by muscovitization. Later, garnet and black tourmaline were formed and still later lithia minerals were deposited, replacing all of the older minerals.

The paper by Landes[75] discusses the detailed paragenesis of two of the central Maine pegmatites. He describes four primary periods of mineralization, of which the first was magmatic and the remaining three hydrothermal. The principal minerals belonging to the first stage are microcline, quartz, muscovite, biotite, black tourmaline, common beryl, and garnet. The second (high temperature hydrothermal) phase minerals are quartz in euhedral crystals, albite (variety cleavelandite), lepidolite, lithia tourmaline, columbite, cassiterite, spodumene, and cesium beryl. Amblygonite and rare phosphate minerals were deposited during the intermediate hydrothermal phase and quartz, cookeite, and purple apatite were formed during the final period.

Subsequent to 1925 a number of papers have been written verifying the hydrothermal replacement concept. In 1926 Schaller and Henderson[76] described replacement of pegmatite minerals in the Embudo area of New Mexico, and somewhat similar observations were made by Roos.[77] Shannon[78] described the replacement of feldspar by albite in a pegmatite in Montgomery County, Maryland.

Schaller[79] repeats his ideas on pegmatite replacement in a paper published in 1927. In this paper he carries the beginning stages back farther: "At present I am inclined to believe that the original rock formed by the magma process was a relatively fine-grained, high-temperature potassium feldspar (probably orthoclase) rock, which on cooling reverted to microcline. . . ." However, no evidence is given for this conclusion.

[75] The inference has been made in several papers published in recent years that the writer's description of replacement in the Maine pegmatites was written after the papers by Hess and Schaller were published. The article in question was published some two months after the Hess and Schaller papers, but it was written many months before. It was accepted as a doctorate thesis at Harvard University on May 1, 1925, and was in the hands of the editor of the *American Mineralogist* when the Hess and Schaller papers appeared in print.

[76] Schaller, W. T., and Henderson, E. P., Purple muscovite from New Mexico: *Am. Mineralogist*, pp. 5–15, Jan. **1926**.

[77] Roos, Alford, Mining lepidolite in New Mexico: *Eng. & Mining Jour.*, **121,** no. 26, pp. 1037–1042, 1926.

[78] Shannon, E. V., Some minerals from the Kensington mica mine, Montgomery County, Maryland: *Am. Mineralogist*, **11,** no. 2, pp. 35–37, 1926.

[79] Schaller, W. T., Mineral replacements in pegmatites: *Am. Mineralogist*, **12,** pp. 59–63, March, 1927.

After a very detailed study of perthites occurring in granite pegmatites Anderson[80] in 1928 advanced the opinion that some perthites are due to replacement by later pegmatitic solutions. During the same year Landes[81] published another paper on pegmatites, this time describing those in the vicinity of Keystone, South Dakota. The phosphate phase is very poorly developed in this area, but there is evidence of two hydrothermal phases following the magmatic stage. The large spodumene logs of the Etta pegmatite are thought to be replacement products of the first hydrothermal phase. A. L. Anderson[82] in a paper on the tin deposits in eastern Washington states: "The minerals of the pegmatite show not only normal crystallization from solutions, but also replacement of some of those first formed. These deposits offer additional evidence that replacement in ore deposits is not confined to veins alone but can occur in pegmatites as well." Late in 1928 Pegau[83] described albitization and later replacement activity of the pegmatites in Amelia County, Virginia. A more complete discussion of the mineral paragenesis of the Virginia pegmatites was published by the same writer in 1932.[84]

During 1929 Megathlin[85] expressed a belief in the existence of several phases of mineralization in the Gilsum, New Hampshire, pegmatites, and Bain[86] described later graphite occurring in pegmatites at Louisa, Quebec.

Southwest Africa pegmatites are described by Frommurze and Gevers[87] in papers published both in 1929 and 1930 in which re-

[80] Anderson, Olaf, The genesis of some types of feldspar from granite pegmatites: *Norsk. Geol. Tidsskrift*, **10**, Nos. 1–2, pp. 116–205, 1928. (Abs. Annot. Bibliog. *Econ. Geol.*, **2**, 2, 507).*

[81] Landes, Kenneth K., Sequence of mineralization in the Keystone, South Dakota, pegmatites: *Am. Mineralogist*, **13**, pp. 519–530; 537–558, Oct., Nov., 1928.

[82] Anderson, A. L., Genesis of Silver Hill tin deposits: *Jour. Geol.*, **36**, pp. 646–664, Oct.–Nov., 1928.

[83] Pegau, A. A., The Rutherford mines, Amelia County, Va.: *Am. Mineralogist*, **13**, pp. 583–588, Dec. 1928.

[84] Pegau, A. A., Pegmatite deposits of Virginia: *Virginia Geol. Survey, Bull.* **33**, 1932.

[85] Megathlin, G. R., The pegmatite dikes of the Gilsum area, New Hampshire: *Econ. Geol.*, **24**, 2, pp. 163–181, 1929.

[86] Bain, G. W., Graphite deposits of Louisa, Quebec: *Econ. Geol.*, **24**, pp. 733–752, Nov. 1929.

[87] Frommurze, H. F., and Gevers, T. W., *Int. Geol. Cong. 15th Session* (So. Africa) *Guide Book Excursion C 21*, **1929.** Gevers, T. W., and Frommurze, H. F., The tin-bearing pegmatites of the Erongo area, South-West Africa: *Trans. Geol. Soc. S. Africa*, **32**, (for 1929), p. 111–149, 1930. (Abs. *Min. Abstr.*, **4**, pp. 411–412; Annot. Bibliog. *Econ. Geol.*, **3**, p. 424).

placement of feldspar by albite and cassiterite is mentioned. Two generations of beryl, one of late hydrothermal age and the other "apparently the first mineral in the pegmatite to crystallize," are discussed briefly by Gedney[88] in an article published in 1930. Buddington[89] in a paper appearing during the same year describes a sequence of mineralization ranging from pegmatite crystallization to zeolite deposition in a molybdenite deposit in southeastern Alaska. Palache, Davidson, and Goranson[90] in discussing the hiddenite pegmatites in North Carolina postulate three stages of pegmatite formation: (1) lit-par-lit pegmatite stage, (2) hiddenite pegmatite stage, (3) hiddenite cavity stage. Fraser[91] applies the sequence of Landes to a pegmatite at Newry, Maine in an article which appeared late in 1930.

A series of hydrothermal pegmatite minerals occurring at Spruce Pine, North Carolina, are described by Ross, Henderson and Posnjak.[92] Their paper was published in 1931. Later in the year a most complete exposition of the hydrothermal replacement theory as applied to the southeastern Manitoba pegmatites was published by Derry.[93] He notes the presence of both "common pegmatites" which contain only potash feldspar, quartz, micas, and sometimes black tourmaline, and "complex pegmatites" in which hydrothermal solutions have deposited albite, cassiterite, lepidolite, spodumene, tantalite, beryl, tourmaline, and other minerals. Derry also discusses the relationship of albite and tin veins to pegmatites.

Kusnezova[94] has recently described the paragenesis of pegmatite minerals in western Georgia (Transcaucasia). The pegmatites are zoned between margins and center, and the presence of pneumato-

[88] Gedney, E. K., Beryllium ores in New England: *Am. Mineralogist*, **15**, p. 120, 1930.

[89] Buddington, A. F., Molybdenite deposit at Shakan, Alaska: *Econ. Geol.*, **25**, 197–200, 1930.

[90] Palache, Charles, Davidson, S. C., and Goranson, E. A., The hiddenite deposit in Alexander County, North Carolina: *Am. Mineralogist*, **15**, pp. 280–302, 1930.

[91] Fraser, H. J., Paragenesis of the Newry pegmatite, Maine: *Am. Mineralogist*, **15**, pp. 349–364, 1930.

[92] Ross, C. S., Henderson, E. P., and Posnjak, E., Clarkeite; a new uranium mineral: *Am. Mineralogist*, **16**, pp. 114; 213–220, 1931.

[93] Derry, D. R., The genetic relationships of pegmatites, aplites, and tin veins: *Geol. Mag.*, **68**, no. 808, pp. 454–475, Oct. 1931.

[94] Kusnezova, E., Materials for the study of pegmatite veins of the Dzirul Massif. Transcaucasia: *Bull. United Geol. and Prosp. Service, U.S.S.R. L. Fascicle* **98**, pp. 1–19, 1931.

lytic and hydrothermal minerals is noted. Piatnitsky,[95] working in the Urals, developed a genetic classification of pegmatites which is given in a subsequent chapter. His "polyphasic" pegmatites are described as follows: "Their body is composed of the consolidated liquid magma yet in this body there remain free spaces and pockets which subsequently are coated or filled with pneumatolytic and hydrothermal minerals." The writer is not in accord with Piatnitsky's conception of the origin of pegmatite cavities, but his ideas on cavity filling are in accord with the modern trend.

CONCLUSIONS. The lateral secretion theory as applied to pegmatites has long been abandoned. Reasons for doubting the applicability of the selective solution theory have been stated. There remains the various modifications of the igneous theory. The writer believes that enough evidence has been amassed to cause acceptance of the hydrothermal replacement theory. However, he believes that in most pegmatites (but little studied because of small size and lack of unusual minerals) a distinctly later hydrothermal phase is absent. These are the "common pegmatites" of Derry[96] and the "simple pegmatites" of this paper. The change in nomenclature is made in order to better contrast this type of pegmatite with the "complex pegmatites" in which mineralization by hydrothermal solutions has taken place. The writer's ideas on pegmatite genesis are briefly given in the following paragraphs.

Pegmatites are a by-product of the crystallization of large bodies of intrusive magmas. The minerals forming during this period of magmatic crystallization do not contain appreciable amounts of water and the other "mineralizers" or "fugitive elements." These become concentrated in the residual magma, a part of which may escape and form pegmatites either in already solidified portions of the parent body or in adjacent country rock. This "pegmatite magma" is naturally more aqueous than the original magma, but it does not approach the degree of attenuation of hydrothermal solutions. It crystallizes in a manner similar to that of an ordinary body of magma, but because of its content of volatile materials the freezing point is lower and coarser crystals will form. Furthermore the degree of reaction between the first minerals to form and the

[95] Piatnitsky, P., Geological explorations in the emerald district in the Urals: *Trans. Geol. & Prosp. Service, U.S.S.R. Fascicle* **75**, pp. 1–71, 1932.

[96] Derry, D. R., The genetic relationships of pegmatites, aplites, and tin veins: *Geol. Mag.*, **68**, no. 808, pp. 454–475, Oct. 1931.

surrounding liquid will be greater than in the less aqueous magmas. Thus albite will penetrate older microcline, producing perthite (the deuteric perthite of Alling[97]), and quartz rods will form in perthite, producing graphic granite.[98] Evidence of both of these late magmatic replacements in the rare earth pegmatite of Llano County, Texas, has recently been described.[99]

With the consolidation of the pegmatite magma the mineralization of the simple pegmatites ceases. The mineralogical character of the simple pegmatite depends upon the composition of the original magma (granitic, syenitic, etc.). The complex pegmatites owe their character to further mineralization by hydrothermal solutions, which dissolve older minerals and precipitate new ones. In some pegmatites this is a long-drawn out process, during which the chemical character of the solutions change so that earlier hydrothermal minerals become unstable and are themselves attacked and replaced. In the larger pegmatites the channelways followed by the solutions do not cover the entire pegmatite, and consequently the hydrothermal minerals are restricted to certain "bands" or "shoots" in the deposit. In some instances the solutions entirely escape from the primary pegmatite and deposit minerals in the country rock. This may explain the lack of hydrothermal activity in the simple pegmatites; the hydrothermal solutions find channelways other than through the primary pegmatite which they prefer to follow.

The immediate source of the hydrothermal solutions may be the original magma, which continues its crystallization after the expulsion of the pegmatite magma. This theory is well stated by Merwin:[100] "(pegmatites) have compositions and structures which have

[97] Alling, H. L., Perthite: *Amer. Mineralogist*, **17**, No. 2, p. 54, 1932.

[98] Vogt (Vogt, J. H. L., The physical chemistry of the magmatic differentiation of igneous rocks: *Skrifter utgitt av Det Norske Videnskaps-Akademi i Oslo, I-Mat.-Naturv. Klasse*, No. 3, second half, **1930**) in describing Fersman's determination of the parallelism in graphic granite between the edge of the unit rhomb of the quartz and the *c* axis of the feldspar, states that this condition is due to the lattice texture of the quartz and feldspar and may be explained only by "a simultaneous crystallization of both minerals." The writer believes that replacement also may be controlled by the lattice structure of the host and guest minerals so as to produce graphic textures.

[99] Landes, Kenneth K., The Baringer Hill, Texas, pegmatite: *Amer. Mineralogist*, **17**, *ppl* 381–390, 1932.

[100] Merwin, H. E., Some associations of ore minerals: *Am. Mineralogist*, **16**, *pp.* 93–96, 1931.

led to the conception that they have been derived from a residuum, or from successive residua, of cooling granite magma. These residua become increasingly hydrous, and enriched in a variety of compounds, which, because of high solubility in the liquid, or slight original concentration, have remained in solution until cooled by intrusion. . . . Reopening of the fissures after periods of cooling allows successive invasions of liquids, each in general presumably cooler than the preceding, and thus in a state of saturation ready to deposit new compounds or to dissolve or react with and replace existing minerals." However, the writer believes that in the larger pegmatites it is quite possible that the hydrothermal solutions are residua of the crystallization of the pegmatite magma itself. At Keystone, South Dakota, the four large pegmatites (Etta, Hugo, Peerless, and Ingersoll) are undoubtedly offshoots of the same parent magma. Each one contains hydrothermal minerals. It is more plausible to believe that the sources of these solutions were deeper-seated portions of each pegmatite than that later solutions from the very much deeper parent igneous body (probably the Harney Peak stock) divided and followed the same pathways that the original pegmatite magmas followed.

Fersman[101] finds that the replacement theory harmonizes with his geochemical studies: "Die 'Replacement' Theorie der amerikanischen Schule bekommt durch diese theoretischen Angaben ihre Erklärung und der Verdrängungsvorgang soll somit als eine theoretisch bedingte Folgerung des Pegmatitprozesses betrachtet werden, besonders in den weit fortgeschritten Phasen des Prozesses" (p. 213).

The hydrothermal replacement theory is also supported in part by recent geophysical investigations. Shepherd[102] has determined that water composes 80 per cent of the volatile material pumped out of Hawaiian lavas when heated in vacuo. Goranson[103] has recently determined that water may be present in natural rhyolite glasses up to 8 and even 10 per cent. A magma of batholithic proportions containing as little as 2 per cent water would have an enormous amount available for hydrothermal activity.

[101] Fersman, A. E., Zur Geochemie der Granitpegmatite: *Min. Petr. Mitt.* (Tschermak), **41,** pp. 200–213, 1931.

[102] Shephard, E. S., The present status of the volcano-gas problem: *Nat. Res. Council, Bull.* **61,** pp. 259–263, 1927.

[103] Goranson, Roy, The solubility of water in granite magmas: *Amer. Jour. Sci.* (5), **22,** pp. 481–502, Dec. 1931.

The geophysicists are not in complete agreement as to whether or not intrusive igneous activity may be accompanied by a gaseous phase. Morey[104] believes that "critical phenomena are never shown by the saturated solutions formed by the cooling magma. . . ." As far as the pegmatites are concerned the field evidence favors Morey's view, for effective replacement necessitates the presence of solutions to carry away the dissolved material.

(To be continued)

[104] Morey, G. W., Relation of crystallization to the water content and vapor pressure of water in a cooling magma: *Jour. Geol.*, **32,** p. 295, 1924.

A SECOND STONY METEORITE FROM NEBRASKA

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In December 1930 the Colorado Museum of Natural History received from Mr. E. W. Black of North Loup, Nebraska, a small sample of a stony meteorite which was said to have been found near Cotesfield, Nebraska, about two years previously. This location at once aroused our interest for the reason that only one aerolite had previously been recorded from that state, namely the Culbertson stone which location is 140 miles southwest of Cotesfield.

The nature of the Cotesfield stone had not been suspected by the finder at first, but its peculiar shape and weight had aroused his curiosity so that he preserved it among some Indian relics which had been the object of his search at the time the stone was found.

The aerolite was purchased by the museum and at the time of its arrival it was complete just as when found, except for the small sample which had been detached and sent in for our examination. Its weight was 2 lbs. 9 oz. or 1160 grams. This stone possessed one very striking characteristic as to form which at once impressed the observer. Its base was almost a perfect plane (Fig. 1), due apparently to the splitting of a larger mass along a cleavage plane, the nature of which it was thought could be determined by cutting the specimen.

The remaining features of its form can best be described by referring to the figures. The entire surface, excepting the base, was coated with a thin fusion crust which was badly discolored by a brown oxide. The base appeared to have been only briefly exposed