PEGMATITE VEINS AND
THE SURROUNDING ROCKS

V. Secondary recrystallization of aplite to form pegmatite

BY

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Abstract: A new mechanism of origin of pegmatite by a process of secondary recrystallization of associated aplite is presented. Secondary recrystallization, driven by the reduction of the total interfacial or grain boundary free energy of a system, involves the growth of relatively few primary grains of a stable matrix by consumption of surrounding grains. The observations of the phenomenon as reported by metallurgists are incorporated into a hypothesis to explain the origin of pegmatites physically and temporally associated with aplite. The applicability of the hypothesis is evaluated with reference to examples from Skjærhalden at Kirköy, southeastern Norway (VOGT, 1931). It is concluded that the formation of these pegmatites and their association with aplite can best be explained by invoking the new hypothesis of formation by secondary recrystallization of the aplite.

CONTENTS

Introduction

A premise of this series of papers is that clues to the origins of pegmatites may be found in the surrounding and associated rocks. Furthermore, I do not believe that there is a single, unique mode of origin of pegmatites. If this is true, then, as in so much of petrology, the determination of genesis is usually by a process of exclusion.* But, for such a process to be valid, one must be aware of all possibilities or the truth may be overlooked in that which has not been considered. The purpose of this paper is to propose a new mechanism of origin of pegmatite to be considered when interpreting the genetic relationships between physically and apparently temporally associated pegmatites and aplites.

Pegmatites may form by a process of metamorphic differentiation (REITAN, 1958, 1960), the material of the pegmatite being derived from the immediately surrounding rock, and the sites occupied by pegmatites may be determined by the deformational history of the associated host rocks (REITAN, 1956, 1959a). A process of metamorphic differentiation might result in primary crystals of relatively large size by slow growth (see, e.g., RAMBERG, 1956, p. 208). Pegmatites may crystallize from a phase introduced from outside of the observable system (REITAN, 1959b). Large crystals might grow relatively rapidly from a fluid of low viscosity (see VOGT, 1931, pp. 87–88, and TURNER and VERHOOGEN, 1960). Pegmatites may also form by a process of secondary recrystallization, a phenomenon reported by metallurgists in simple systems under controlled conditions. It is the intention here to explore the applicability of this mechanism to complex geologic systems which have reached their present state under conditions not directly observed but deduced.

Pegmatite and aplite

The term *pegmatite* will be used as defined by ANDERSEN (1931, p. 3):
'Pegmatites are mineral associations crystallized in situ, decidedly more coarse-grained than similar mineral associations in the form of

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* 'It is an old maxim of mine that when you have excluded the impossible, whatever remains, however improbable, must be the truth.' Sherlock Holmes in *The Beryl Coronet* by Arthur Conan Doyle.

ordinary rocks and differing from these in having a more irregular fabric of the mineral aggregates.' Two requirements imposed by this definition are 1) coarseness and 2) irregularity of grain (see also TUR-NER and VERHOOGEN, 1960, p. 423). Common also are graphic inter-growths, textures indicative of replacement, and a composition approximating granite (see, e.g., BARTH, 1962, p. 124), quartz and feldspar predominating.

Aplites differ from pegmatites in fabric and in grain size. ROSEN-BUSCH (1907, p. 582) says the typical fabric of aplite is panidiomorphic, meaning that no constituent takes its boundaries exclusively from its neighbours (note: *not* that every grain is bounded by crystal faces). The grain size of aplites is typically uniformly fine. Aplites are poor in mafic constituents, as are pegmatites, though both names are applied to an extensive range of chemical and mineralogical compositions.

In spite of the striking differences of fabric and granularity, a close genetic relationship between aplite and pegmatite has been sug-gested. ANDERSEN (1931, p. 28) has noted the '...co-occurrence of pegmatite and aplite in small pegmatite bodies...' and, in larger peg-matites, '...as a rule [aplite] forms irregular masses scattered among the coarse-grained minerals.' USPENSKY (1943), observing inclusions of pegmatoid aggregates in aplite dikes and aplitic borders of composite dikes, argued that aplites can be transformed into pegmatites by re-crystallization and replacement under open-system conditions. JAHNS (1955, p. 1102) refers to many examples where the close physical and apparent temporal association of aplites and pegmatites suggests a genetic relationship.

Secondary recrystallization

Secondary recrystallization, also called exaggerated or discontinuous grain growth, is a special type of grain growth by recrystallization in which a few grains (MAY and TURNBULL, 1958, say about one in 10^5 primary grains) grow at the expense of many primary grains (see, e.g., BOWLES and BOAS, 1948; DUNN, 1953; DUNN and KOH, 1958). For secondary recrystallization to occur most grains of the matrix must be stabilized, i.e., the total free energy of most of the primary grains — including the interfacial energy — must be rather equal. The total interfacial energy of grains will be dependent on the size

of the grains (influencing total surface area), the crystallographic orientation on either side of the grain boundaries, the degree of grain boundary strain, and perhaps compositional differences of adjacent grains and impurities along grain boundaries (DE VORE, 1959). The boundaries of certain grains may (e.g., by virtue of favourable orientation, other factors being suitable) break away from their 'pinned' positions, resulting in the growth of a few grains by the consumption of surrounding grains.

The driving force of the process is the reduction of total free energy of the system accomplished by the replacement of high energy boundaries by low energy boundaries and a total reduction of boundary area, that is, the reduction of interfacial energy. A favourable situation for secondary recrystallization would be a primary grain with low average interfacial energy between itself and its neighbours surrounded by primary grains which themselves have a uniformly high average interfacial energy, thus constituting a stable matrix. Stability of the matrix is enhanced by uniformity of grain size, grain shape, and distribution of phases and adsorbed constituents.

MAY and TURNBULL (1958) have shown that secondary recrystallization in silicon-iron with a dispersed second phase is dependent on temperature. At low temperature little happens — grain growth is minimal. When the kinetic energy of the system is very great, recrystallization is enhanced *in general* and selectivity of grain growth due to differences in grain boundary energy is eliminated, general coarsening of grain size being the result. However, at a definite temperature — when the kinetic energy of the system is just sufficient — selective growth by secondary recrystallization may occur and those grains of low average interfacial energy may become very large. It should be noted that this selectivity does not necessarily imply a change in the ratios of the interfacial energies (e.g., of differently oriented grains) as a function of temperature, but may be principally an expression of differences in the ratios of the rates of grain growth by secondary recrystallization as a function of temperature.

Secondary recrystallization stops when the growing grains impinge on one another. Grains of low average interfacial energy will not consume other grains with equally low average interfacial energy.

Rigorous treatments of the criteria for grain growth, the driving force for secondary recrystallization, effect of grain boundary curva-

ture, and of inclusions in idealized, simple models which are subject to mathematical analysis have been given by DUNN, 1953; DUNN and WALTER, 1959; and MAY and TURNBULL, 1958. What follows is an attempt to apply the observational and theoretical data in a qualitative manner to geological circumstances.

Genesis of pegmatite from aplite

It is proposed that some of the occurrences of physically associated and apparently temporally and genetically related aplites and pegmatites may be explained as a consequence of secondary recrystallization of a primary aplite to form pegmatite.

The genesis of aplite is outside of the scope of this discussion; its presence is assumed as the starting point. However, the aplitic texture is thought to be fundamental to the hypothesis.

Secondary recrystallization requires a stable matrix of uniformly relatively high interfacial energy. The typical fabric of aplites, if representative of a low energy shape and distribution arrangement of the components, would, presumably, be more common than it is. The uniformly fine grain size implies large and uniformly distributed surface area per unit volume of rock. For these reasons the texture typical of aplite is believed to fulfill the requirements prerequisite to secondary recrystallization.

General statement of the hypothesis

At an appropriate temperature (and perhaps stimulated by passing fluids) certain of the grains in an aplite begin to grow at the expense of their neighbours by virtue of their lower total grain boundary free energy. Grain growth by secondary recrystallization would simply involve reorientation of the crystal lattice of many grains that are consumed. Transport of material to the extent that it occurs, would be limited to distances on the order of the radii of the recrystallized grains. Grain size of the pegmatite produced would be determined by the density of the spacing of suitable 'nuclei' for secondary recrystallization and the temperature during the recrystallization. Under appropriate conditions recrystallization might be so selective as to account for the crystallographic orientation sometimes observed in
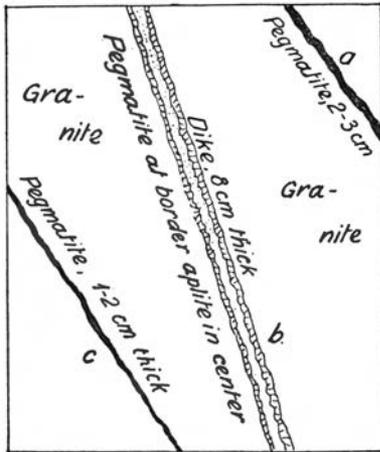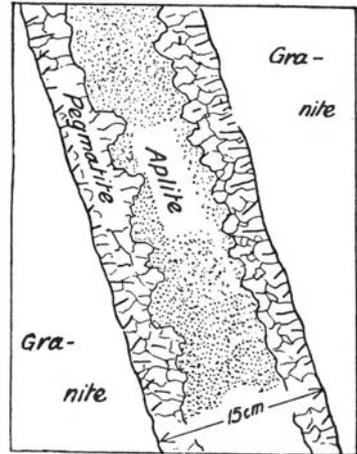
Fig. 1.

Fig. 2.

graphic granite texture (FERSMANN, 1928) and other intergrowths
seen in pegmatite which are attributed to simultaneous crystallization.
Certain preferred orientations of crystals (relative to vein walls and
zones) may be controlled by the influence of grain-to-grain orientation
on the total interfacial energy and preferred orientation of 'nuclei'
as a result of an original weak orientation fabric in the aplite in
response to the conditions during the primary crystallization (e.g.,
isotherms or flow parallel to the walls). The irregular masses of aplite
within pegmatite or pegmatite within aplite would be interpreted as
manifestations of secondary recrystallization having stopped before
all the aplite was consumed. Zonal relationships between aplite and
pegmatite might be, e.g., a consequence of a zonal arrangement of
isotherms or a zonal distribution of suitable nuclei for secondary
recrystallization due to compositional or textural zoning within the
primary aplite.

Application to specific examples

Figures 1–4 are reproduced from VOGT (1931, pp. 58–59) and illustrate
the association of aplite and pegmatite in small veins. All of the
examples are from a single small area at Skjærhalden at Kirköy, within
the Iddefjord granite, southeastern Norway. Illustrated are examples
of pegmatitic borders with aplitic centres (Figs. 1 and 2), pegmatite
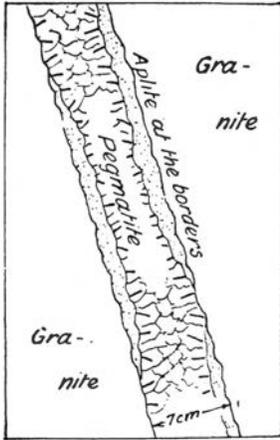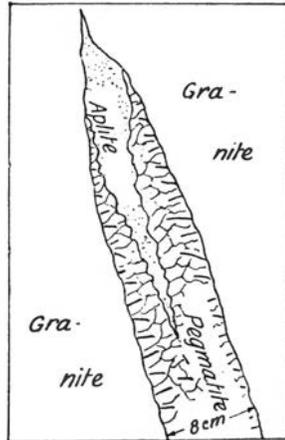
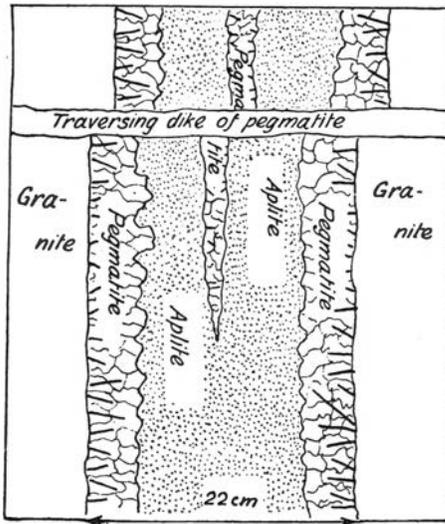Fig. 3a.   Fig. 3b.

Fig. 4.

centre and aplite at borders and at the end (Fig. 3, a and b), and a combined case of pegmatitic borders and discontinuous centre separated from the borders by aplite, the whole being traversed by a young pegmatite (Fig. 4).

These examples are incapable of satisfactory explanation by proposing differences in the amounts of dissolved volatiles in fluids

introduced, as immiscibility of a volatile-rich and a volatile-poor silicate magma phase across a small vein is impossible. Neither is there any reasonable mechanical explanation to account for the distributions of pegmatite and aplite if two stages of introduction of fluid are proposed. Nor does the proposal by USPENSKY (1948) of recrystallization of aplite under the influence of streaming fluids seem satisfactory, as there are no miarolitic cavities or other evidence of an avenue along which such fluids might have passed. Any explanation as a result of metamorphic differentiation seems at best contrived.

Therefore, by a process of exclusion, the mechanism seeming applicable and their being no contrary evidence available, an explanation by secondary recrystallization of aplite is invoked in accordance with the comments included in the general statement of the hypothesis.

BENEDICT (1960) described many examples of aplite-pegmatite dikes at Tenaya Canyon, Yosemite National Park. She distinguished 2 main types of pegmatite associated with aplite dikes and concluded that pegmatites of type-A crystallized initially as coarse-grained aggregates. Of pegmatites of type-B, which normally occur along the borders of dikes and but rarely as zones or stringers in dikes, she says that the anhedral crystals somewhat elongate perpendicular to dike walls '... give the impression that they grew from the walls inward, encroaching on the aplite core zone' (p. 70), and notes sliver-like relics '...of multigranular material of aplitic grain size apparently isolated in a large feldspar grain of the border zone' (p. 116). She concludes that '... interstitial vapor along some dike margins and other surfaces of discontinuity promoted recrystallization of aplite to form pegmatite type B' (p. 147). Similarity of mineralogy, both qualitatively and quantitatively, and of chemical composition, including potassium-sodium ratios, of the aplites and type-B pegmatites support this conclusion.

It appears that BENEDICT (1960) has, in effect, invoked the mechanism proposed here without specifying the process in detail, to explain the association of some aplites and pegmatites in the area she studied in the Sierra Nevada.

Conclusion

An additional possibility to be considered when interpreting the genetic relationships between physically and apparently temporally associated pegmatites and aplites has been proposed. It is not proposed

to account for all pegmatites. From examination of some of the litera-
ture on aplites and pegmatites, the hypothesis might be applicable
to some of the associations described by VOGT (1931) and BENEDICT
(1960), as discussed above, ANDERSEN (1931), DERRY (1931), and
KING (1948), and might help in some cases to explain some of the
features characterized as common to the association of aplites and
pegmatites in general discussions (see, e.g., HATCH, WELLS, and
WELLS, 1961; GROUT, 1932).

Acknowledgements

REFERENCES

ANDERSEN, OLAF, 1931. Discussions of certain phases of the genesis of pegma-
    tites. Norsk geol. tidsskr. v. 12, pp. 1–56.
BARTH, T. F. W. 1962. Theoretical Petrology, 2nd Ed. John Wiley & Sons,
    Inc., New York, 416 pp.
BENEDICT, REBA W. 1960. Aplite-pegmatite dikes of Tenaya Canyon, Yose-
    mite: A study of their structures, textures, and mineralogy. Dissertation,
    University of California, Berkeley, 227 pp.
BOWLES, J. S. and BOAS, W. 1948. The effect of crystal arrangement on second-
    ary recrystallization in metals. J. Inst. Metals, v. 74, p. 501.
DERRY, D. R. 1931. The genetic relationships of pegmatites, aplites, and tin
    veins. Geol. Mag. v. 68, pp. 454–475.
DE VORE, G. W. 1959. Role of minimum interfacial free energy in determining
    the macroscopic features of mineral assemblages. I. The model. Jour.
    Geol. v. 67, pp. 211–227.
DUNN, C. G. 1953. Secondary recrystallization textures and their origin in cold
    rolled single crystals of silicon-iron. Acta Met. v. 1, p. 163.
— and KOH, R. K. 1958. On formation of nuclei for secondary recrystalli-
    zation in silicon-iron. Trans. Am. Inst. Met. Eng. v. 212, pp. 80–84.
— and WALTER, J. L. 1959. Tertiary recrystallization in silicon-iron:
    Trans. Am. Inst. Met. Eng. v. 215, pp. 465–471.
FERSMANN, A. E. 1928. Die Schriftstruktur der Granitpegmatit und ihre Ent-
    stehung. Zeits. Kristall. v. 69, pp. 77–104.
GROUT, F. F. 1932. Petrography and Petrology. McGraw-Hill Book Company,
    Inc., New York, 522 pp.

HATCH, F. H., WELLS, A. K. and WELLS, M. K. 1961. Petrology of the Igneous Rocks, 12th Ed. Thomas Murby & Co., London, 515 pp.

JAHNS, R. H. 1955. The study of pegmatites. Econ. Geol., 50th Anniv. Vol., Part II, pp. 1025–1130.

KING, B. C. 1948. The form and structural features of aplite and pegmatite dikes and veins in the Osi area of the northern provinces of Nigeria and the criteria that indicate a nondilational mode of emplacement. Jour. Geol. v. 56, pp. 459–475.

MAY, J. E. and TURNBULL, David, 1958. Secondary recrystallization in silicon iron. Trans. Am. Inst. Met. Eng. v. 212, pp. 769–781.

RAMBERG, HANS, 1956. Pegmatites in West Greenland. Geol. Soc. America Bull. v. 67, pp. 185–214.

REITAN, PAUL H. 1956. Pegmatite veins and the surrounding rocks. I. Petrography and structure. Norsk geol. tidsskr. v. 36, pp. 213–239.

— 1958. Pegmatite veins and the surrounding rocks. II. Changes in the olivine gabbro surrounding three pegmatite veins, Risör, Norway. Norsk geol. tidsskr. v. 38, pp. 279–311.

— 1959a. Pegmatite veins and the surrounding rocks. III. Structural control of small pegmatites in amphibolite, Rytterholmen, Krageröfjord, Norway. Norsk geol. tidsskr. v. 39, pp. 175–195.

— 1959b. Pegmatite veins and the surrounding rocks. IV. Genesis of a discordant pegmatite vein, St. Hansholmen, Risör, Norway. Norsk. geol. tidsskr. v. 39, pp. 197–229.

— 1960. The genetic significance of two kinds of basified zones near small pegmatites. Int. Geol. Congress XXI, Part XVII, pp. 102–107.

ROSENBUSCH, H. 1907. Mikroskopische physiographie der massigen gesteine, Tiefengesteine-Ganggesteine, 4th Ed. E. Schwizerbartsche Verlagshandlung, Stuttgart, 716 pp.

TURNER, F. J. and VERHOOGEN, JOHN, 1960. Igneous and metamorphic petrology, 2nd Ed. McGraw-Hill Book Company, Inc., New York, 694 pp.

USPENSKY, N. M. 1943. On the genesis of granitic pegmatites. Amer. Mineral. v. 28 pp. 437–447.

VOGT, J. H. L. 1931. The physical chemistry of the magmatic differentiation of igneous rocks. III. 2nd half: Skr. Norske Vid.-Akad. Oslo, I. Mat.-Naturv. Klasse 1930. No. 3, 242 pp.