Geology. — *Tectonics of the Mt. Aigoual pluton in the southeastern Cevennes, France.* Part I. By D. DE WAARD. (Communicated by Prof. H. A. BROUWER.)

(Communicated at the meeting of March 26, 1949.)

1. *Introduction.*

In the summer of 1947 detailed tectonic field-work was carried out in the southeastern Cevennes of France. The purpose of the investigation was to tackle structural problems in the little-known granite massif near the Mt. Aigoual. This massif is shown in the southwerstern corner of sheet Alais of the French geological map, 1 : 80,000, as a red dot of granite stretching away to the north in slates. Mapping has been done in and around this granite dot (fig. 1) in a purely structural sense. The well-exposed country in this part of the Cevennes facilitated detailed study, though mapping proved to be hampered sometimes by glacial deposits, hillside waste and afforestation. Excellent exposures are provided by a large number of small rivers.

During the survey, the area of the red dot of granite on the geological map appeared to comprise a small batholith surrounded by a complicated pattern of granitic, porphyritic and dark coloured dikes in the slaty country rock. The large scale map at the back shows the geological units of the mapped area.

The author's thanks are due to Professor W. NIEUWENKAMP for helpful discussions and criticism in field and laboratory, to Mr. R. C. HEIM for valuable data and good companionship during the field-work and to Miss D. E. WISDEN, M.Sc., Southampton for assistance with the English.

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2. *Synopsis of literature.*

The Central Plateau is situated in the middle of France as a large isle of mainly metamorphic and crystalline rocks with a local cover of young volcanic material on its peneplained surface, surrounded by Mesozoic and Tertiary sediments (fig. 1).

The age of the metamorphic rocks has long been uncertain. The "Archean age" theory has been rejected since the discovery of Cambrian and Ordovician fossils. Precambrian rocks are still mentioned however. According to most authors, folding and metamorphism of the Palaeozoic geosynclinal strata has taken place in the Sudetic phase of the variscan orogeny. The tectonic units with metamorphic imbricate and nappe structures have been analysed especially by the studies of DEMAY (e.g. 1931b, 1934), summarized by VON GAERTNER (1937).

Also from this part of France granitization phenomena are extensively

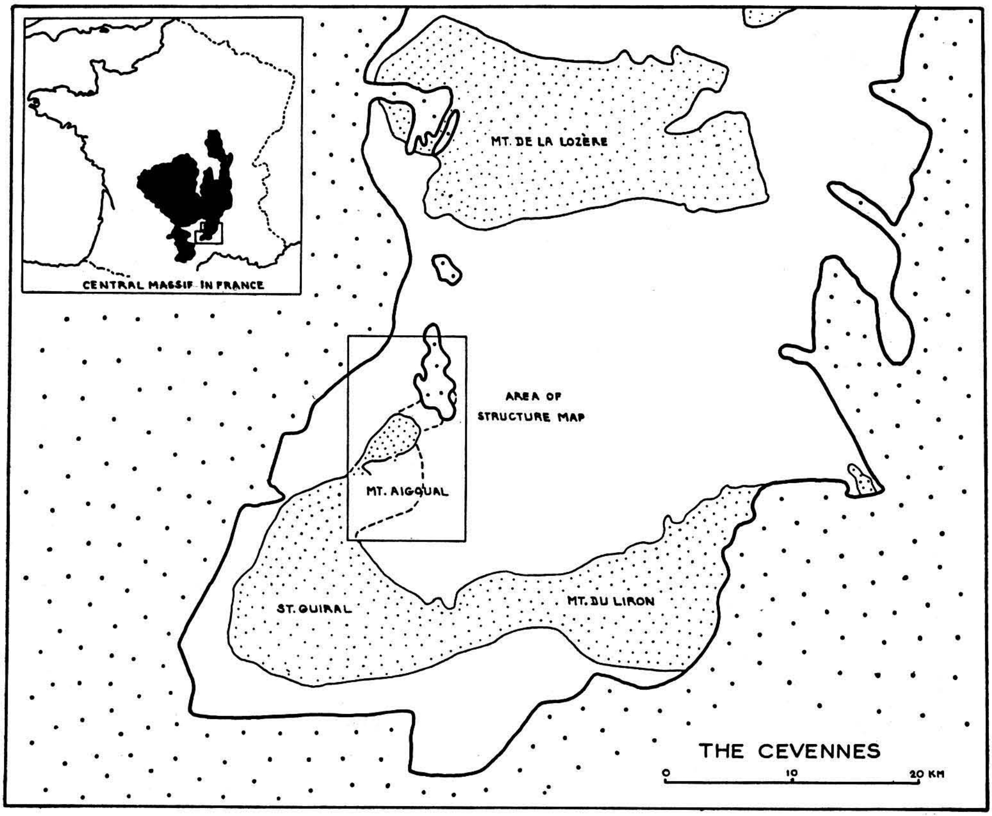


Fig. 1. Map of the southeastern part of the Central Massif showing the geographical position of the mapped area between slates (white) and adjoining granite massifs (dotted). The surrounding mesozoic strata are coarsely dotted.

described by French authors (e.g. DEMAY, 1935, 1942, RAGUIN, 1930, 1946, ROQUES, 1941). According to these publications the granite plutons in the Central Massif may be distinguished in 'pretectonic', 'syntectonic anatectic', 'synkinetic intrusive' and 'posttectonic intrusive' with respect to the Middle Carbonian orogeny. There seems to be no apparent relation between anatectic and intrusive granites. No rule could be laid down for the mode of occurrence, or for the texture of the posttectonic intrusive granites. Sometimes they are porphyritic, but syntectonic plutons too may have a similar texture (ROQUES, 1941, RAGUIN, 1946).

The Mt. Aigoual granite pluton, subject of this paper, is briefly mentioned in several French publications (e.g. BERGERON, 1889, 1904, DEMAY, 1931a). According to all authors it is a posttectonic intrusion, cutting the schistosity of the slates. A narrow metamorphic aureole is further evidence of its intrusive character. The texture of the granite is described as homogeneous and porphyritic, with large crystals of orthoclase. Because of similarity in these properties, connections are postulated with the adjacent St. Guiral pluton. The Mt. Aigoual pluton is mentioned by DEMAY (1931a) as an apophyse of the much larger St. Guiral massif.

The first mapping of this area was achieved by FABRE and CAYEUX (1901) in sheet Alais of the geological map of France and for the second edition by THIÉRY (1923). Of the numerous granitic dikes north and south of the granite body only a few have been mapped separately in this sheet. Those nearer to the intrusive body are lumped together in one large granite outcrop extending southward as far as the St. Guiral massif.

The morphological study of BAULIG (1928) of the Central Plateau, as well as his maps, show many faults and fault-blocks. Two of these faults, continuing in one are drawn through the Mt. Aigoual granite. In the mapped area, however, little evidence for these faults could be found.

According to VON GAERTNER (1937) and based on DEMAY (1931a), the Mt. Aigoual region forms part of the Orthocevennes complex, a pennine nappe-like tectonic unit of the Central Massif. The granite of the Mt. Aigoual, together with the southern adjacent massif, is mentioned and drawn in section by VON GAERTNER as a late orogenic (posttectonic) intrusive sheet, flatlying in the cleavage plane of the slates.

3. *Geology.*

In the centre of the mapped area a small elliptical pluton of granite crops out surrounded by slates. The granite body, 5 km long and 2,5 km wide is very homogeneous; no endomorphism could be observed.

The granite is a light coloured, black and white rock of coarse grained texture with 10—15 cm long idiomorphic phenocrysts of orthoclase. Main components are quartz, orthoclase, plagioclase and biotite. Thanks to the granite-porphyritic texture, planar and linear flow structures could be measured nearly everywhere in the pluton. Joint systems occur usually in a variety of directions; only in few cases have slickensides been formed. Aplite, lamprophyre and quartz porphyry dikes have been observed inside the granite massif.

Nearly everywhere round the granite body results of contact metamorphism are visible. The contact plane is always sharp; its strike and dip vary locally.

The country rock farther away from the contact is in general slaty. According to DEMAY (1931a) a Cambrian age of the slates would be probable. The slates are not subdivided on sheet Alais of the geological map of France; on sheet Séverac, some kilometers west of the mapped area, a probable Potsdamian age is indicated.

Normally the slate is veined with white quartz. Though differing in quantity, usually numerous thin veins and lenses as well as small dikes to 40 cm wide occur. Intensely folded veins have been observed. They do not penetrate in joint systems or faults and very seldom in cleavage planes.

In several parts the slaty rock is a well-developed phyllite. Locally quartzite layers parallel to the schistosity of the slates are observed; elsewhere microscopical folds in bedded slates cross the cleavage planes. Spotted slates too are found in some places.

Usually the slates possess one or two systems of ribs on their cleavage planes. In the south of the mapped area they have minor folds with wave lengths between 10 and 100 cm. In this region they often pass into folded gneiss. Directions of ribs and fold axes as well as cleavage planes and joint systems in the country rock have been measured for structural purposes.

Dikes cut through the country rock round the pluton. Granitic dikes in large numbers present themselves as a fringe-like extension of the pluton. This edging has a limited extension at the northern and eastern side. Dikes are found much farther towards the south, but they are almost absent on the western pluton border.

Lamprophyre dikes occur in groups, mostly outside the edging of granitic dikes. They are often intruded along the cleavage planes of the slates. Their occurrence within the granite and in porphyry dikes prove them to be younger. More basic dike rocks have been observed.

Quartz porphyry dikes of light coloured material with phenocrysts of quartz and also of both quartz and orthoclase are observed between granite dikes and inside the granite pluton. They cross granitic dikes and are crossed by lamprophyre dikes.

Faults and faultzones, with and without drag, occur frequently in the mapped region. Faults cutting dikes have not been found. In one case drag is observed in the country rock at the contact with a granitic dike. Quartz veins always are disturbed by faulting; quartz does not occur within the fault fissures, only crushed in fault breccia.

The geological history in the mapped region according to the observed phenomena may be summarized in the following succession.

Sedimentation of strata probably in Cambrian time. Folding and metamorphism accompanied by exudation of quartz (according to most authors in the Middle Carbonian, Sudetic phase of the variscan orogeny). Development of schistosity and joint systems. Both segregation of quartz and jointing will be products of the same cause, the latter somewhat younger than the former. Intrusion of granite accompanied by contact metamorphism and intrusion of quartz porphyry, lamprophyre, aplite and pegmatite.

4. *Petrology and microtectonics.*

The microscopic compositions and microtectonic features of the mapped rocks will be mentioned here in brief. The petrology of the Mt. Aigoual area is discussed in a separate paper by HEIM (1949).

The granite of the pluton is a coarse-grained, light-coloured rock with up to 15 cm large twinned automorphic phenocrysts of white K-feldspar.

Main components are white K-feldspar, plagioclase, dark grey grains of quartz and many small black biotite crystals dispersed through the rock and in a dark rim around the large feldspars. Thin sections show Carlsbad-twinned orthoclase, much albite- and pericline-twinned oligoclase, brown biotite, quartz and occasionally hornblende. According to the mineralogical composition the rock may be classified in the granodioritic subdivision of the granites *sensu lato*. Quartz shows in general slight undulatory extinction.

In the field little difference could be observed between the granite in the pluton and in the dikes. The latter may show however some more variation in size of the smaller minerals between the large feldspars. Quartz too may thus have an automorphic habitus, giving the rock frequently a granite-porphyritic texture. In that case the quartz phenocrysts are corroded and rounded. Evidence of stronger dynamo metamorphism in the granite dikes is shown by wide-spread and strongly undulatory extinction of quartz and by bent and frayed biotite crystals. Sometimes recrystallised nonundulatory, suture-grained parts within quartz crystals do occur. The microscopic texture as a rule is lacking in orientation.

The quartz porphyry dikes contain a light-coloured, dense rock with many automorphic, dark-coloured quartz grains and irregularly distributed feldspar phenocrysts. The dikes are sharply jointed in small regular blocks. The rock is composed of quartz, orthoclase, biotite and albite phenocrysts in a dense, partly spherulitic or micrographic groundmass of mainly quartz and orthoclase. The quartz phenocrysts are largely corroded and rounded and sometimes show undulatory extinction.

Dikes of a dark quartz porphyry have been mapped within the granite body, near the contact of the pluton, cutting through granitic dikes and forming bordering zones of the latter. It is a dark rock of biotite and amphibole with quartz and plagioclase phenocrysts and a few K-feldspar phenocrysts. Under the microscope this rock proved to be a tonalite porphyry. Large rounded, corroded and undulatory quartz phenocrysts, zonal, Carlsbad-, albite- and pericline-twinned, corroded andesine, brown biotite, hornblende and occasionally orthoclase phenocrysts are enclosed in a fine-grained groundmass, often with fluidal texture, of andesine, biotite, hornblende and some quartz.

As mentioned above different types of basic rocks have been observed. They show difference in darkness, in quantity of feldspar and in size and orientation of biotite. Usually they are dark coloured, fine-grained, glittering rocks, largely composed of biotite and feldspar. In dike outcrops they often show rounded blocks caused by weathering along joints or they may be weathered all through into yellow-brown, spotted, sandy material. In some dikes the rock has an oriented texture, due to relatively large biotite crystals, being arranged parallel to the dike contacts.

Most dikes have kersantite-like composition; one consists of greenish-grey porphyrite.

The aplite dikes normally contain quartz, orthoclase and some biotite; no exceptional minerals have been found in the aplites, nor in the few pegmatite or runite dikes and veins.

The country rock is usually microfolded slate with quartz veins, phyllitic with sericite and recrystallised quartz, blastophyllitic with garnet and kyanite, and schistose to almost gneissic with sericite, muscovite, biotite, chlorite, quartz and some albite. In the narrow contact zone a fine grained gneiss is locally developed with orthoclase and plagioclase. Andalusite, sillimanite and cordierite also have been observed near the contact.

5. *Granite contacts.*

Many exposures allowed a detailed observation of the pluton borders. The western contact forms a nearly straight line in the plane of the structure map. Slates border the granite along a sharply defined contact plane which dips, at an angle of 70° to 55°, under the slate. This contact has all the aspects of a set of joints, a pre- or syn-intrusive joint system without doubt, because of the existing contact metamorphism in the slate. A narrow zone of slightly metamorphosed slates and phyllites borders the contact with penetrating veins of aplite and pegmatite. No offshoots such as granitic dikes are to be found on this side of the pluton.

Joint-like contact planes have been observed nearly everywhere around the pluton. The northern border is complicated by the branching off of many dikes. These offshoots, splitting apart euhedral blocks of slate, could be observed in detail. It has not been feasible however to reproduce these complications in the structure map; the curved lines merely represent a general outline of the granite body in these places. The northern contact planes show great variety of orientation; steep discordant and low angled often concordant contacts have been measured. Blocks of slates, surrounded by granite dikes could be observed.

Contact metamorphism in the north and northeast of the pluton may locally be stronger than near the western border, though more than one meter of the country rock has usually not been changed megascopically. The slates are transformed in these places in a fine-grained gneiss often veined or brecciated with aplite and occasionally with pegmatite. The slates and metamorphosed country rock near the contact show variations in strike and dip. Dips proved to be usually steeper and strikes are systematically bent to northeasterly direction.

Parts of the eastern and southeastern contacts are hidden by hillside waste. Where visible the same joint-like contact planes with shallow metamorphism, acid veins and offshoots of granitic dikes occur. Here too, strikes and dips of the slates change near the contact. The contact plane usually dips under the slates with varying angles.

On the map there are two gaps in the southern border. In the eastern one the contact loses itself under debris. In the western gap there has been no occasion for mapping further south; it seems quite possible however that across this track a bottleneck may join up the Mt. Aigoual pluton with the St. Guiral massif. The southern contact too has little contact metamorphism. Gneiss and acid veins are observed; mostly there is hardly any change beyond a hardening of the country rock.

Though the contact may be clean and sharp as in the western border, complicated contacts have been found. In a river exposure of the northern contact the following details have been observed. The granite near the contact, being quite normal with dark inclusions and at most a little less large orthoclase crystals is bordered by a small tonalite porphyry dike of 20 cm followed by a quartz porphyry dike of 30 cm thickness with inclusions. Then, along the contact there is a kind of conglomerate zone, 25 cm thick with rounded pieces of granite and metamorphosed slate in a fine-grained crystalline matrix. On the outer side of the contact and parallel to it a second tonalite porphyry dike cuts the slightly metamorphosed and hardened slate. In the south an exposure is found with the succession of normal granite, a 3 m zone of somewhat darker granite, a 50 cm zone of granite, normal in colour but more crowded with large orthoclase crystals than usual, a 75 cm dike of tonalite porphyry in contact with hardened slate of which a slice of 5 m is cut off by a quartz porphyry dike running parallel with the contact.

Still less of metamorphism has been found near the contacts of the granite or granite porphyry dikes, though local differences occur.

The contacts of the granite massif, usually cross-cutting and occasionally concordant with the slaty cleavage and the slight but never missing contact metamorphism points undoubtly to an intrusive character of the granite. As a whole the pluton seems to be bordered by joint systems. They must have been developed before or during the intrusion. During the intrusion movement along these joint systems has taken place. The intrusion has been accompanied by an uplift of the country rock. This is proved by strike and dip alterations near the contact. Post-intrusive movements along contact planes cannot have been of much importance because of the uninterrupted zone of contact metamorphism.

The contact zone described above with rounded granite and gneissic pebbles in a fine-grained crystalline mass, points to intrusive movements along this plane by which parts of both sides of the contact were crushed, rounded and embedded in a fluidal mass, causing an intrusion bordering mylonite.

6. *Outline of tectonic phenomena.*

The main point of the investigations has been to collect tectonic data in order to work out the movements and origin of the granite pluton. A summary is given in the structure map at the back. The detailed mapping in a relatively small area, with heights between 800 and 1400 meters, made it desirable to have all data transposed in one horizontal plane of 1000 meter. Topographic distortion is eliminated in this way. The structure map shows as it were a hypothetical peneplain at 1000 m in this area. Most measurements have been made near this 1000 m plane.

A fairly close network of tectonic data has been collected in the granite massif. Special attention was given to fluidal phenomena and fracture systems in order to be able to reconstruct the intrusive movements. Slickensides and directions of dikes were likewise of much importance with regards to these movements. Marginal observations on contact planes and inclusions complete the network of structural data.

In the country rock many important tectonic features could be measured. Strike and dip of cleavage planes of the slates are disturbed near the contact as mentioned in the preceding paragraph. Joint systems, ribs and minor folds in the slates give details of pre-intrusive tectonics. Dike measurements will possibly reveal relations between pre-intrusive tectonics and intrusive movements. Faults with drag phenomena may be connected with block movements during the intrusion.

These tectonic data, plotted in equiareal diagrams, will be discussed systematically in the following paragraphs.

7. *Flow structures.*

Flow structures in the Mt. Aigoual granite are mainly marked by oriented orthoclase crystals and, in its marginal parts, also by small inclusions.

The orthoclase crystals are mostly tabular after (010) and elongated in the direction of the *c*-axis. Their orientation may be linear with parallelism of the *c*-axes or planar with parallelism of the (010) planes. Usually they are twins after the Carlsbad law, showing interrupted (001) cleavage on their narrow sides.

Primary flow phenomena in crystalline rocks may be divided into linear and planar structures. Ordinarily one of the two is predominant or exclusive in a massif. Only when there are suitable minerals can both these flow structures be seen. Feldspar is one of these, because of its elongated tabular shape. In the Mt. Aigoual granite planar structures are favoured for its feldspars are distinctly more tabular than columnar in shape.

In spite of the possibility of recognizing flow structures by measuring the directions of the phenocrysts, their orientation at a first glance seems to be chaotic in many places. Only a careful investigation of several surfaces of different orientation of the granite reveals a predominant arrangement. A judicious choice of the order in which the surfaces are investigated, e.g. horizontal planes first, followed by surfaces at right angles to it assists in deciding between linear and planar orientation. In the latter case a surface parallel to this plane of flow was selected in order to reveal any tendency to a linear arrangement within this plane. As a rule only after a prolonged scrutiny and with many measurements of generally existing, local directions on many different planes of the granite, could the predominant orientation be detected. Thus the field observations do not consist of measurements of single feldspar crystals which could only give reliable information if a large number (e.g. 100) were treated at each locality, but of measuring predominant directions on fairly large surfaces of granite outcrops.

Parallelism of minerals is caused by differential motion in the intrusive mass. Consolidation preserved a record of the ultimate movements. Linear parallelism is originated by preponderant one-dimensional elongation of the mass. Stretching in one direction results in a parallel orientation of the longest axes, the *c*-axis of the feldspars, in that direction. Their (010) planes have arbitrary positions rotated about the *c*-axes (fig. 2b). If differential motion in the mass effects equal stretching in all directions within (shortening normal to) a plane, planar parallelism will develop.

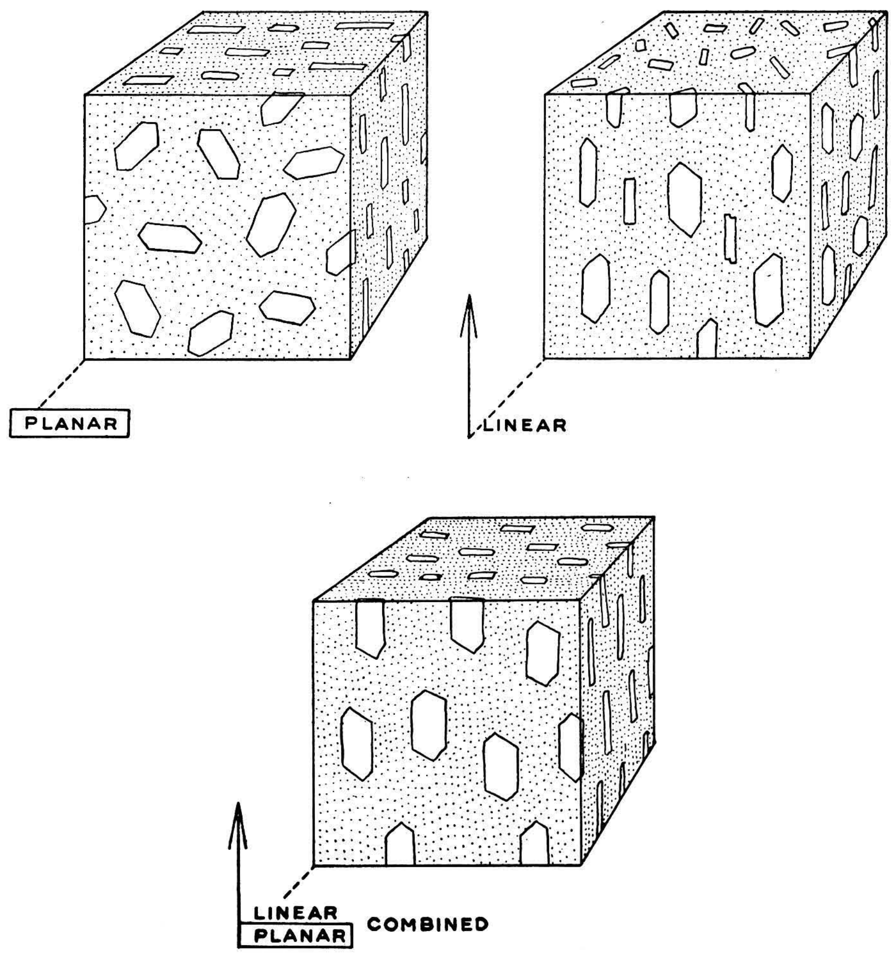


Fig. 2. Ideal arrangement of feldspar phenocrysts in primary oriented granite. *a.* (010) planes of feldspars in planar arrangement. *b.* c-axes of feldspar crystals in linear orientation. c. combination of linear flow structure by parallelism of c-axes and planar flow structure by platty arrangement of (010) planes.

Feldspars will tend to have (010) parallel to this plane, while their elongated *c*-axes show haphazard orientation (fig. 2a).

In the intermediate case, when planar structures are developed together with somewhat stronger stretching in a certain direction within this plane, both (010) planes are oriented in planar parallelism and *c*-axes in linear parallelism in the same plane (fig. 2c). Only locally are linear and planar orientation found associated; usually one of the two is predominant and the other weak or absent.

Because differential motion is strongest near the contacts of intrusions flow structures will be developed very well in their marginal parts. Conversely strongly oriented structures in the central part of the intrusion indicate that considerable differential movements also in these parts of the mass have existed. Usually these structures are planar. If linear parallelism exists too, strong one-dimensional stretching has been predominant. In parts of the intrusion where no planar structures are developed a weak linear orientation may be formed by distinct expansion of the pluton in a certain direction.

The movements of flow are very well determined if both planar and linear flow structures could be measured. Planar parallelism shows the plane along which flow has taken place and linear parallelism the direction of flow in that plane.

8. *Intrusive flow.*

The general aspect of the registered and interpolated flow data in the structure map of the pluton suggests comparison with a pan of boiling porridge. In at least three sections of this relatively small pluton upward culmination of flow is recorded.

This reconstruction is based on about 65 flow determinations. Construction of flow planes and lines is done by interpolation of the measured data in the least complicated way. These lines record in a nice manner the last movements of the intrusive mass before ultimate consolidation. The given interpolation is a reconstruction in the simplest way; in reality the flow structures may be much more complicated in detail.

West of the centre of the pluton a half concentric doming is made visible by flow phenomena. It has varying but mostly rather steep flow structures, planes as well as lines. The planar structure has conformable contacts with the westerly border, dips to the south against another, incompletely-known doming and continues to the E.N.E. To the north, structures are more complicated but presumably still conformable with the pluton contacts, continuing into dike offshoots. Conformable structures are also well-developed in granite dikes. Linear parallelism in north and west cross flow plane strikes nearly perpendicularly, indicating probably a strong upward flow. Near the top of the doming the lineation grows parallel with planar structures.

In the north-east of the pluton the continuation or easterly flank of the doming is found. As far as observed it has identical conformable structures. Flow lines here may show stronger convergence in upward flow, also from northerly directions.

Flow structures in the south-east are different. They seem to be conformable to parts of the southern contact but disconformable to the easterly wall rock, representing a mass with parallel oriented planar structures, complicated by vertical and changing dip directions. They suggest a lacking or hidden part of the mass still S.E. of the southern pluton border.

These structures might have been caused by motion of a mass ascending from south-easterly direction; a northward motion which produces at the same time a drawing-out of the northern doming or elongation of the northern part of the pluton in S.W.—N.E. direction. Such an elongation may have originated the flow lines in that direction, which are bent in the central part of the pluton.

In the south-western part of the pluton a fragmentarily-known small doming is visible. The same parallel and steep flow lines as in the south-eastern section have been found in the south-western appendix or bottleneck.

All together the flow structures in the pluton suggest an upward moving mass, converging from all directions, which was strongly affected by the ascending mass from the south, causing the elongation and bending out of the northern doming.

9. *Fracturing of granite.*

In the pluton joint systems are found in amazing quantity. Normally the Mt. Aigoual granite is fractured by about six different systems of joints in each locality. Up to twelve systems have been measured in some places. By fracturing the granite falls apart in different sized and irregular blocks, frequently parallelepipe and column shaped. In fresh rock, joint planes are hardly visible; in a few cases faint marks of dislocation are observed. The explanation of the existence of fracturing may be contraction during cooling of the granite, or continued motion within the pluton after consolidation of the upper shell, or a combination of both causes. In either case, however, the resulting fracture systems cannot be quite arbitrary, there certainly will be a relation with the fabric of the rock and the shape of the massif.

The connection of flow structures and some joint systems is advocated by HANS CLOOS, BALK and others. They make a distinction between e.g. cross joints perpendicular to flow lines and longitudinal joints parallel to them. Many joint systems could not be placed systematically by these authors.

In the case in question it proved always to be possible to find some of the six or twelve joint systems in regular association with flow structures. But there is nothing specific which marks the thus found "cross" or "longitudinal" joints; apart from their relations to flow structures nothing may distinguish them from the other fractures. Most joints however cannot be explained with reference to these directions of use; they seem to be useless from tectonic point of view. In this case it would be a rather arbitrary application, to select and use "cross" joints, etc., according to recipe.

In the method here applied all measured joint data are used in a statistical diagram. This is done in order to bring out clearly the possible regularities of jointing in the pluton as a whole. Though it has proved, so far, not to be possible to arrange all existing joint systems according to structural or other principles, this of course in no way excludes the possibility of a systematic arrangement. There may be suggested here a systematic coincidence between the fracturing of the rock and its mechanical properties in different directions. Any alteration in equilibrium of the mass, e.g. during cooling, contraction, renewed motion etc., will thus cause systematic joint systems. They cannot all be explained locally, but they will relate as a whole to the fabric of rock and massif.

Measurements of joint systems have been made at regular intervals throughout the pluton outcrop. An average diagram of fracturing of the pluton may reveal special regularities in the structure of the massif. Projections of poles of all joint planes are plotted in an equal area net, thus giving a petrofabric analysis of the whole pluton as far as its joints are concerned. Fig. 3 shows the statistical pole diagram of 80 measured joint planes.

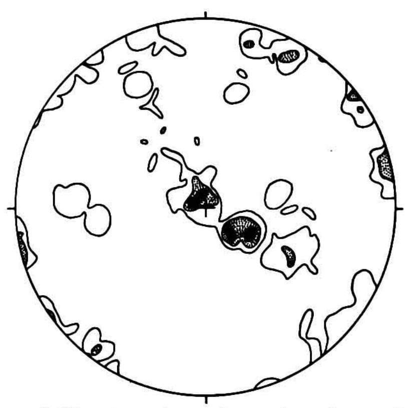


Fig. 3. Pole diagram of 80 joints throughout the pluton. Contours 5—4—2½ %
(Southern hemisphere as in fig. 5, 6, 7, 9 and 10.)

The first striking regularity is the evident symmetry of the diagram. The N 120 E. central line of the diagram shows the same density distribution at both sides. The direction of this symmetry plane harmonizes with shape and directions of flow structures of the pluton except for the south-western corner. Probably this symmetry in the diagram is connected with the predominant motion in the direction of the line of symmetry and with the mentioned probability of supply of granite mass from a south-easterly direction.

By further analysis of the diagram two girdles may be observed. They resemble *B*-tectonites or a cross girdle diagram in petrofabrics, one NW—SE and the other horizontal, crossing each other at right angles. This indicates an orientation of nearly all measured joints either parallel to a horizontal NE—SW axis or in a more or less vertical arrangement.

Because joints largely will be related to, or oriented as a result of the fabric of the rock, in this case the only visible variable viz. flow structures, this diagram may show an average orientation of joints associated with the average orientation of flow. A glance at the structure map shows a predominance of flow lines in NE—SW direction which may be associated here with domination of cross joints in the densest parts of the horizontal girdle viz. in the NE and SW of the diagram.

In the same way a relation does not seem accidental between the densest part of the vertical girdle in the middle and south-east of the middle of the diagram with the ascent of mass from a south-easterly direction. This densest part of the diagram indicates the nearly everywhere observed "bedding planes" or primary flat-lying joints throughout the pluton.

10. *Dikes and faults in the pluton.*

Besides numerous ordinary fractures described in the preceding paragraph, dikes and faults have been observed in the pluton. In this paragraph joints filled with aplite, lamprophyre and porphyry and faults with well-developed slickensides or with visible dislocation will be discussed. More than fractures they may be expected to furnish information about motion in the rigid or semirigid upper part of the pluton. These data are plotted in the structure map.

The discussion of these phenomena is hampered however, by their limited number. The pluton body proved to be relatively poor in aplite dikes. Three of them may be called of cross joint origin, two are along primary flat-lying joints, two others show affinity to longitudinal joints and the few remaining cannot be labelled according to flow structures and shape of the massif. It will be clear that use of this nomenclature has no practical value here for tectonic purposes because of the small quantity of data. The few measurements of lamprophyre and porphyry dikes cannot be used either.

Faults usually with striae could be observed clearly in the north-western sector of the pluton. They are plotted in tectonogram fig. 4. The diagram is composed of equiangular projections of: a fault zone striking N 37 E, dipping steeply W; the sharp bisectrix N 50 E, 7 S of a system of diagonal joints or faults, crossing each other nearly perpendicular (84°); horizontal striae in a fault zone striking N 45 E; and three sets of striae on different fault planes in one locality, striking in a north-western direction and dipping S. The last three fault systems with striae are likely to represent the result of the same direction of motion recorded on different planes in this locality; combined they may give the direction of the original motion, viz. S (1.2.3.) in the diagram, striking N 38 E and dipping 25 SW.

These plotted data show remarkable conformity; they have uniform directions between N 35 E and N 50 E, with gentle dips, mostly to the

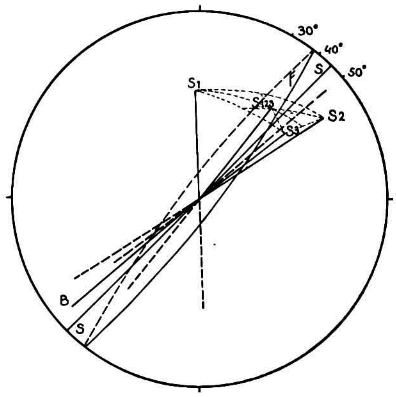
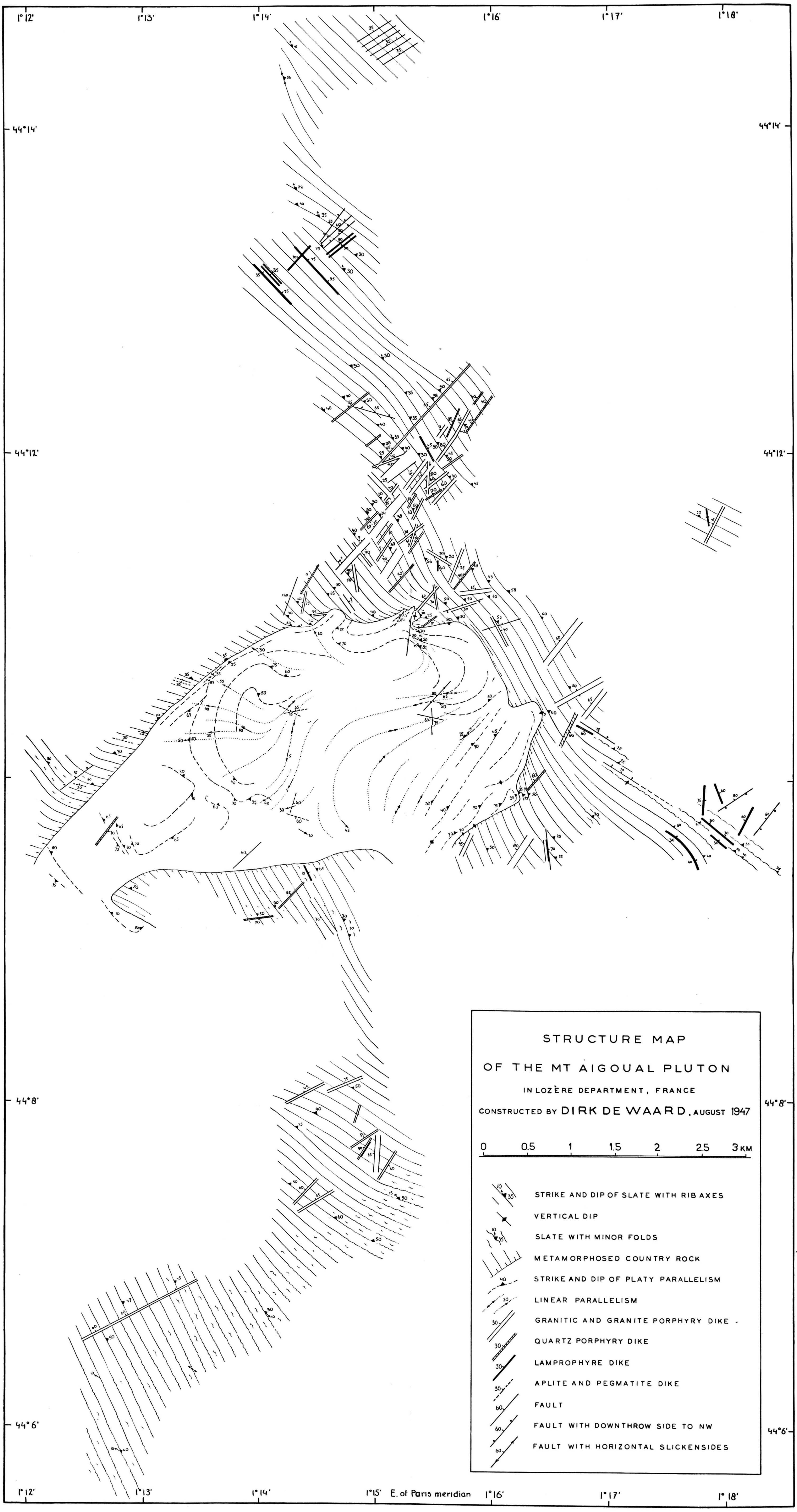


Fig. 4. Tectonogram of faulting and slickensiding in the north-eastern sector of the pluton. Equiangular projections of striae (S), the sharp bissectrix of diagonal joints (B) and a fault zone without striae (F). (Projections in the northern hemisphere.)

SW. Thus, motion is recorded in the rigid upper shell of the granite in SW—NE direction, slightly upward to the north-east.

In an earlier phase of the consolidation, motion in the same direction has taken place in the area north-west of the centre of the pluton. Two aplite dikes are several times broken and irregularly dislocated by sets of parallel steep faults, striking about N 40 E. Bent parts of the aplite dikes and fixing of the fault planes indicate a semirigid condition of the granite in which SW—NE motion has occurred.

The SW—NE motion thus found in the northern part of the massif may be interpreted as a result of differential expansion of the pluton in that direction during the last phases of the intrusion. Similar indications have been found by means of flow structures in earlier intrusive phases.


STRUCTURE MAP
OF THE MT AIGOUAL PLUTON
IN LOZÈRE DEPARTMENT, FRANCE
CONSTRUCTED BY DIRK DE WAARD, AUGUST 1947
0 0.5 1 1.5 2 2.5 3 KM
STRIKE AND DIP OF SLATE WITH RIB AXES
VERTICAL DIP
SLATE WITH MINOR FOLDS
METAMORPHOSED COUNTRY ROCK
STRIKE AND DIP OF PLATY PARALLELISM
LINEAR PARALLELISM
GRANITIC AND GRANITE PORPHYRY DIKE
QUARTZ PORPHYRY DIKE
LAMPROPHYRE DIKE
APLITE AND PEGMATITE DIKE
FAULT
FAULT WITH DOWNTHROW SIDE TO NW
FAULT WITH HORIZONTAL SLICKENSIDES
1° 12'
1° 13'
1° 14'
1° 15' E. of Paris meridian
1° 16'
1° 17'
1° 18'
44° 14'
44° 12'
44° 8'
44° 6'