B. R. G. M.

Département GEOTHERMIE

GL01443

AREA France

THE DEVELOPMENT OF GEOTHERMAL ENERGY IN FRANCE

Based upon a press release
by the Ministère de l'Industrie, du Commerce et de l'Artisanat

1978

France has relatively good low energy geothermal resources i.e. hot groundwater with temperatures under 150°C. These resources were first inventoried for the Paris Basin and the general study on this subject has been available for several months at the Documentation Française. Inventories are now being made for other regions covering the South West of France, the Massif Central (especially the Limagne region) and the Rhine corridor where the study is being made in cooperation with West Germany and will concern resources on both banks of the Rhine.

The use of geothermal resources for heating purposes results in substantial energy savings. For a heating season at Creil involving 4,000 dwelling units the energy savings in comparison with conventional types amounted to approximately 50 %. This was the first season for geothermal energy use and all operational problems had not been solved.

The average saving per dwelling unit is from 1.5 to 2 tonnes of oil-equivalent and the average price difference for an operation involving 2,000 units is about 8 to 10 million.

The government promotes the use of geothermal energy by covering the risk involved and making advance grants at very low interest rates to be paid back if the project is successful. This advance grant roughly covers the expenses for the original drilling. The success or failure of the drilling is determined by several parameters i.e. the existence of the geothermal deposit, groundwater temperature and the rate of flow of the well.

The Geothermal Committee has decided to equip 20,000 dwellings with geothermal heat. Work is now in progress for 12,000 units of this total (cf. annex I : List of Operations). Although there has been a considerable number of contracts for geothermal work, the rate of application has been slowed down up to now principally by three factors i.e. competition from conventional energy methods, changes in construction programs and problems involved in implementing geothermal operations.

Competition from Conventional Energy Sources

Up to July 1977, some regions favored energy solutions such as the generalised use of electricity or gas. EDF - GDF allowed bonuses for dwellings equipped in this way and also supplied the distribution network to the subscribers to contracts of this kind without charge. The government progressively established more normal competition between all forms of energy and since 1977 it has eliminated certain discriminatory arrangements.

Energy costs have progressively become more realistic and for this reason a more balanced system of competition has been developed.

Changes in Construction programs

The last three years were characterised by the recent economic crisis. One of the consequences was a considerable change in construction perspectives and programs. There were generally delays in planned operations and there was a tendancy towards a type of habitat consisting of individual homes and small collective buildings in preference to the large projects.

This tendancy led the government to consider using geothermal energy not only for new construction but also for existing dwellings. In order to allow the latter to use the new forms of energy it was necessary to make it possible to modify existing contracts for heating. These modifications are now possible as a result of the Law of 19 July 1977, article 3 bis, III and V. Geothermal energy can now be used when contracts are renewed for heating or heating installations.

Problems involved in implementing geothermal operations

During the last thirty months it became clear that the implementation of a geothermal program involved problems at the financial and technical levels. These are relatively expensive operations often involving tens of millions of francs and requiring the application of several different techniques (drilling, pipings, heating). Few organisations exist in France capable of carrying out such operations. The government therefore considered measures tending to diversify market supply by favoring the establishment of a corporation whose capital would be owned by several public bodies (Union Nationale des H.L.M., SCET-ECAL, Crédit Foncier, B.R.G.M., etc...). The objective of this company will be to promote the operations financially and it will make use of various technical bodies for the utilisation of geothermal resources.

In addition to the beneficial effect which its activity will have on competetive conditions, this company will obtain better costs through integrated operations. It will become operational in the next few months. Its mission is to pass on the savings made in this way to residents so as to reduce heating costs for the latter.

Research on geothermal energy

Since 1974 research on geothermal energy has been carried on by several public and private bodies (B.R.G.M., C.E.A., C.N.R.S., E.D.F., I.F.P., ELF AQUITAINE). The D.G.R.S.T. provides coordination for these activities which consist essentially in feasibility studies (calorie use scheme) special technical studies (for example on corrosion) and inventories of the various basins which were mentioned above. A program for the possible use of hot and dry rock as artificial geothermal reservoirs is now being examined and cooperation on this subject with West Germany is under consideration.

The Community program for indirect action is oriented towards the following subjects : data collection, heating of buildings (low temperature energy), electricity production (high temperature energy) and hot and dry rock.

The national and Community programs are very well coordinated.

Use of low energy geothermal resources for low temperature thermodynamic systems

The use of hot springs for the operation of thermodynamic systems capable of producing electricity is under consideration. It is clear that systems of this kind can be profitable only in areas which are not part of an energy distribution network. Since France has already made progress in the use of thermodynamic technique the Délégation aux Energies Nouvelles is considering experimenting with a system of this kind in France so as to create a "demonstration model". This system is mainly for export or for insular regions which have hot springs like in the overseas Departments and Territories.

In view of the special character of the hot springs used and the fact that they are often superficial it was decided to call this technique "thermal electricity" so as to distinguish it from electricity production from high energy geothermal resources which is the only type known today.

Perspectives

In view of the perspectives ot he VIIth Plan and the structures and means which are now in existence, the annual rate for the equipment of dwellings with geothermal heat can be estimated as 50 to 60,000 dwelling units after 1980.

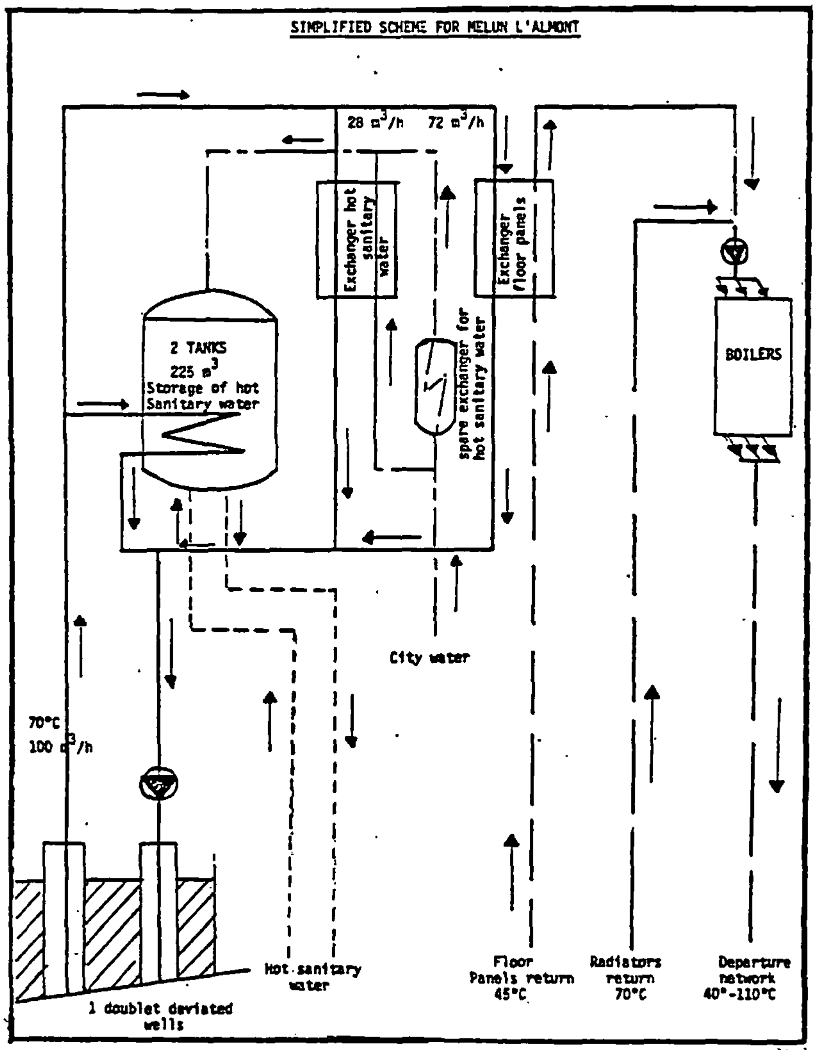
This rate of new use should continue for about ten years and then progressively fall up to the end of the century so that towards the year 2000 there will be about 800,000 housing units equiped in this way.

50,000 to 60,000 housing units per year represent about thirty operations and 80 to 90 % of these operations will be carried out at geothermal sites where reinjection is necessary, principally in the Paris Basin, Limagne and Alsace. Consequently about fifty drillings per year will be necessary.

These approximations are sufficient to indicate the future perspectives for the heating industry and the manufacturers of tubing and heat exhangers.

These perspectives may be reviewed and reduced in terms of the use of hot springs by thermal plants. If the hot springs are used in this way there will naturally be a reduction in the number of drillings but there will be an increase in the use of tubing for the transport network.

MELUN L'ALMONT



- Reservoir tapped by 1 doublet, with deviated wells (deviation : 20° with respect to vertical).

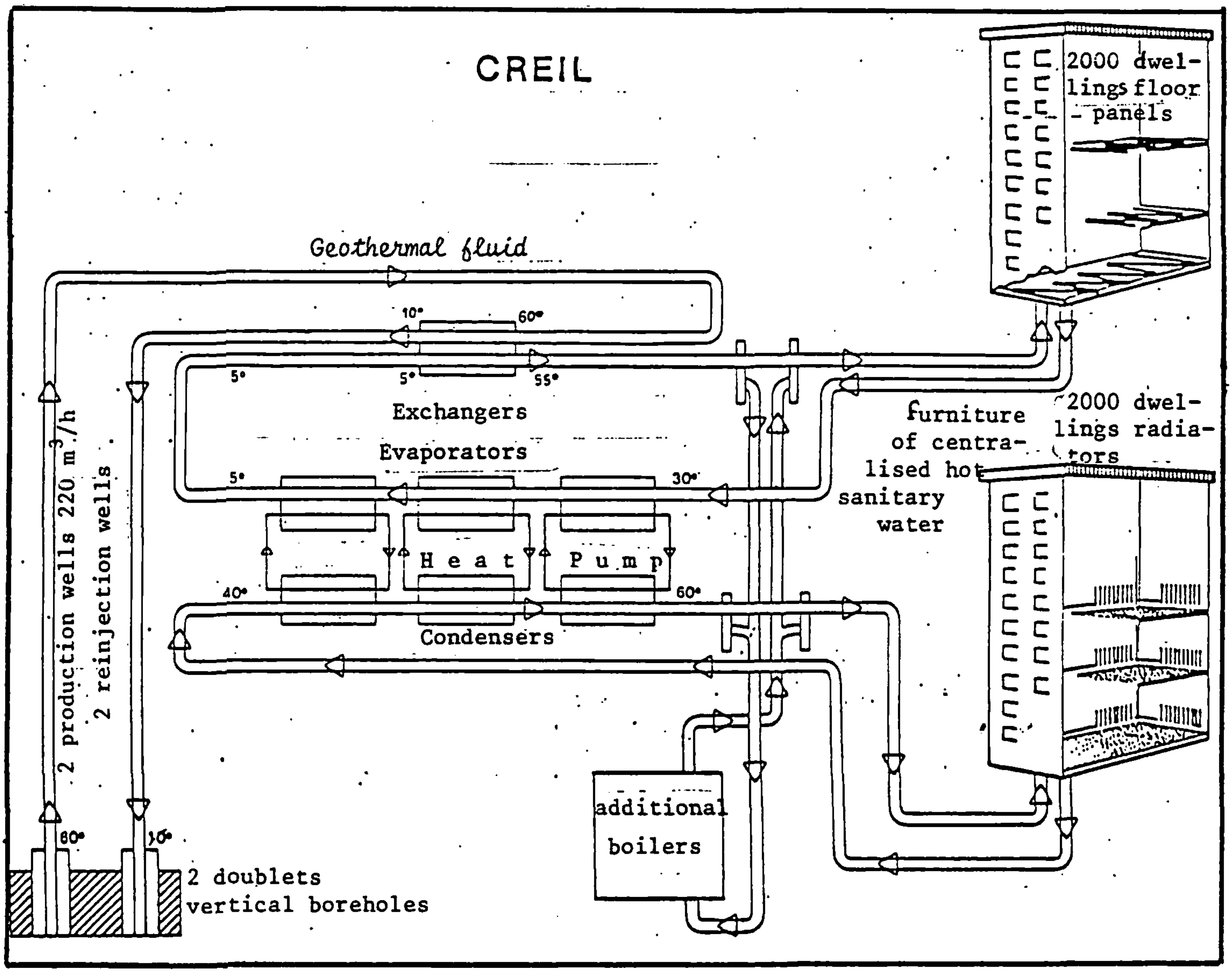
- Total depth reached : 1 800 meters.

- Flow rate during winter season : 90 m^3/h artesian.

- Well head temperature : 70°C.

- Number of dwellings involved : 3 000 heated with radiators and floor panels. Geothermal fluid covers 100 % of furniture of heat sanitary water and heating of "floor panels" returns.

- Primary energy savings per year : 1 500 t. oil-equivalent.



- Reservoir tapped by 2 doublets (2 reinjection wells, 2 production wells. Total depth of boreholes = 1,650 meters.

- Actual rate of flow during winter : 220 m^3/h (maximum potential rate : 300 m^3/h).
  (140 m^3/h by pumping + 80 m^3/h artesian).

- Well head temperature : 57°.

- Number of dwellings involved = 4,000 - 2,000 heated by floor panels, 2,000 by radiators with supply of hot sanitary water.

- 100 % of hot sanitary water supplied throughout the year from geothermal sources.

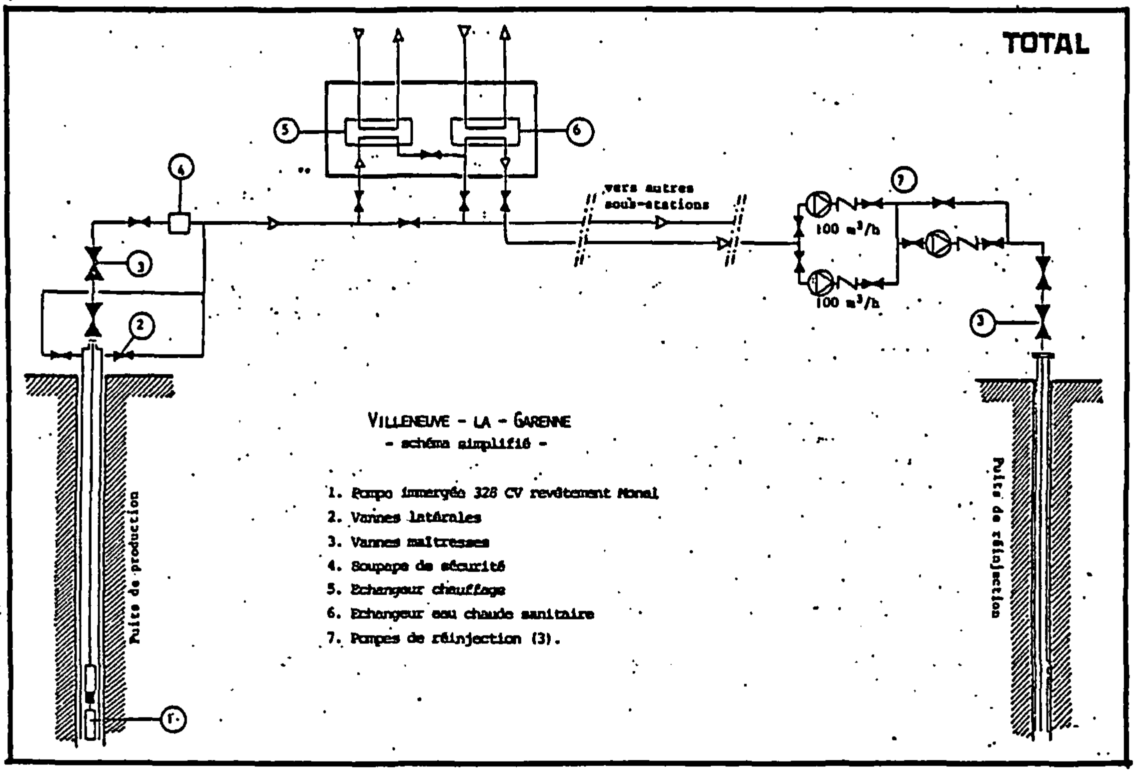
- Heating 100 % covered by geothermal sources for outside temperatures higher than 11°C.

- Heating 100 % covered by geothermal sources + heat pumps for outside temperature between 11°C and 8°C.

- Heating covered by geothermal sources + heat pumps + additional boilers for outside temperatures under 8° C.

- Expected primary energy savings through use of geothermal sources : 4,000 - 5,000 t oil-equivalent.

VILLENEUVE LA GARENNE



- Reservoir tapped by 1 deviated doublet (25° in relation to perpendicular). Total depth of boreholes : 1,800 meters.

Production tubing made of fiber glass.

- Present rate of flow in winter : 180 m^3/h by pumping.

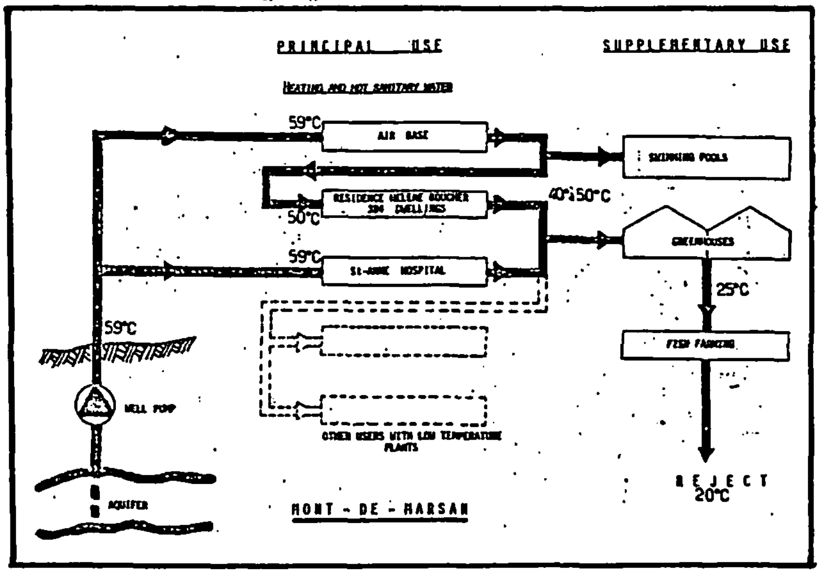
- Well head temperature : 58°C.

- Number of dwellings involved : 1,800.

- The geothermal water network is made of fiber glass with heat insulation and is supplied separately by 10 exchangers (5 for heating and 5 for hot water household use) located in 5 sub-stations.

- Annual primary energy saving through use of geothermal sources : 2,000 t oil-equivalent.

MONT - DE - MARSAN



- Reservoir tapped by a production well (no reinjection).
  Total borehole depth : 1,850 m.

- Well head temperature = 59°C.

- Pumping rate of flow (with possible modulation) : 120 m^3/h and 300 m^3/h.

- The well feeds into a fiber glass network connected as follows :

  . In series with the air base of Mont-de-Marsan (conventional plant 85/65° at -5°C, heating + hot sanitary water), and the Résidence Hélène Boucher (384 dwellings heat with floor panels).

  . In parallel with St Anne Hospital (heated by a conventional plant with centralised supply of hot sanitary water).

- In a later phase, it is planned to connect to the network a barracks which is now being renovated.

- Estimated annual primary energy savings : 2,000 to 3,000 t oil-equivalent.

MELUN-MÉE SUR SEINE (UNDER CONSTRUCTION)

- 1 doublet under construction (production well completed, reinjection well being drilled).
- A second doublet is planned.
- Total depth of boreholes : 1 800 m.
- Artesian flow obtained during tests on production well : 187 m^3/h.
- Temperature at well head : 71°C.
- Estimated number of dwellings involved : 6 000 housing units in the final stage.
- Estimated annual primary energy savings through use of geothermal sources : 9 000 t oil-equivalent.

Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, vol. 2, 1958.

P/1241 France

Geology of Uranium Vein Deposits of France

By J. A. Sarcia, H. Carrat, A. Poughon and H. Sanselme *

Since the creation of the Commissariat à l'Energie Atomique in 1946, the Exploration and Mining Administration of this organization directed its efforts toward exploration of the Hercynian massifs of France, being guided in this by the knowledge of certain already-exploited European deposits (in Bohemia and Portugal) and also by the presence of such secondary minerals as autunite and torbernite in Morvan and especially in the vicinity of the town of Autun, to which the mineral autunite owes its name.

The explorations were fruitful, and it was found that uranium-bearing veins in Hercynian massifs constitute the bulk of French uranium reserves.

Four mining divisions—Forez, established in 1946; Grury, in the Morvan (1946); La Crouzille, in northern Limousin (1949); and Vendée (1952)—are located (Fig. 1) in different parts of the Hercynian Massif Central of France, the first two being in its eastern branch and the other two in its western branch.

All deposits and all indications of mineralization are found in, or in the immediate neighborhood of, Hercynian granites, or more exactly, granulites. Let us explain what we mean by this term.

According to the French school of petrography, granulite is a two-mica granite in which muscovite strongly predominates over biotite; we reserve the term granulitic granite for the reverse case; we do not consider relative quartz content, for it does not appear to be sufficiently characteristic.

We call all rocks " granulitized " in which muscovite, including the various micas known as " sericite ", is developed at the expense of feldspars and biotite, either on a megascopic (Northern Limousin) or a microscopic scale (Forez).

In this sense, our granulites and granulitic granites are, in effect, granites granulitized in varying degrees; they are the only rocks to which the term " granulites " in its classical sense can rigorously be applied, quartz content being this time characteristic of the rocks occurring in dikes and lenses in the late " intrusions ", which constitute the country rock of our deposits and which, curiously enough, do not themselves show any signs of primary uranium mineralization.

THE FOREZ MINING DIVISION

Created in 1946 and located at first in Lachaux and later (since 1955) at Saint-Priest-la-Prugne, the Division of Forez of the Commissariat à l'Energie Atomique has explored a vast region comprising the Forez Mountains proper, which rise between the Loire and Allier rivers on the volcanic plateau of Velay, and the Bourbonnaise Mountain, which rises to the north of them.

Indications of uranium mineralization on the western slopes of Bourbonnaise Mountain near the village of Lachaux have been known for some time. They were included in a radium concession granted in 1927. No mining was done in this area, however, and it was not until the creation of the Commissariat à l'Energie Atomique that the Lachaux deposits were explored in a systematic way (this was done between 1947 and 1954). Reconnaissance was not limited to the boundaries of the old concession. The C.E.A. parties extended their activities to the entire Forez Range and the exploration is now almost complete. This work outlined two new uraniferous areas: the region of Bois Noirs, discovered in 1951 and now being exploited; and the region of Ambert, which has been under investigation since 1955.

Geologic Setting

The Forez Mountains include two petrographically distinct units.[1] The northern part extends to the southern boundary of the Bois Noirs region and consists of Hercynian intrusive granites. The southern part lies in the metamorphic core of the Massif Central. This is essentially a region of migmatites: anatexites and anatexite granites (Fig. 2). The region was affected by two tectonic movements: Hercynian and Alpine. The former produced silica-filled fractures trending in three main directions: northwest to southeast, north-south and east-west, Variscan trends being rare. The latter fracture raised the southeastern border of the Massif Central. This caused fracturing of the core along north-south faults dipping sharply to the east, as well as overthrusting of the eastern blocks over the western ones along these faults, which are generally superimposed upon Hercynian dislocations.

It is impossible, in this article, to describe all of the explored indications of uranium, which exceed a hundred. We may, however, divide them into three mineralogically and morphologically distinct types, each being the dominant one in each of the three regions named above.

The Lachaux concession contains deposits of parsonsite and other phosphates.

Original language: French.

* Commissariat à l'Energie Atomique, France.

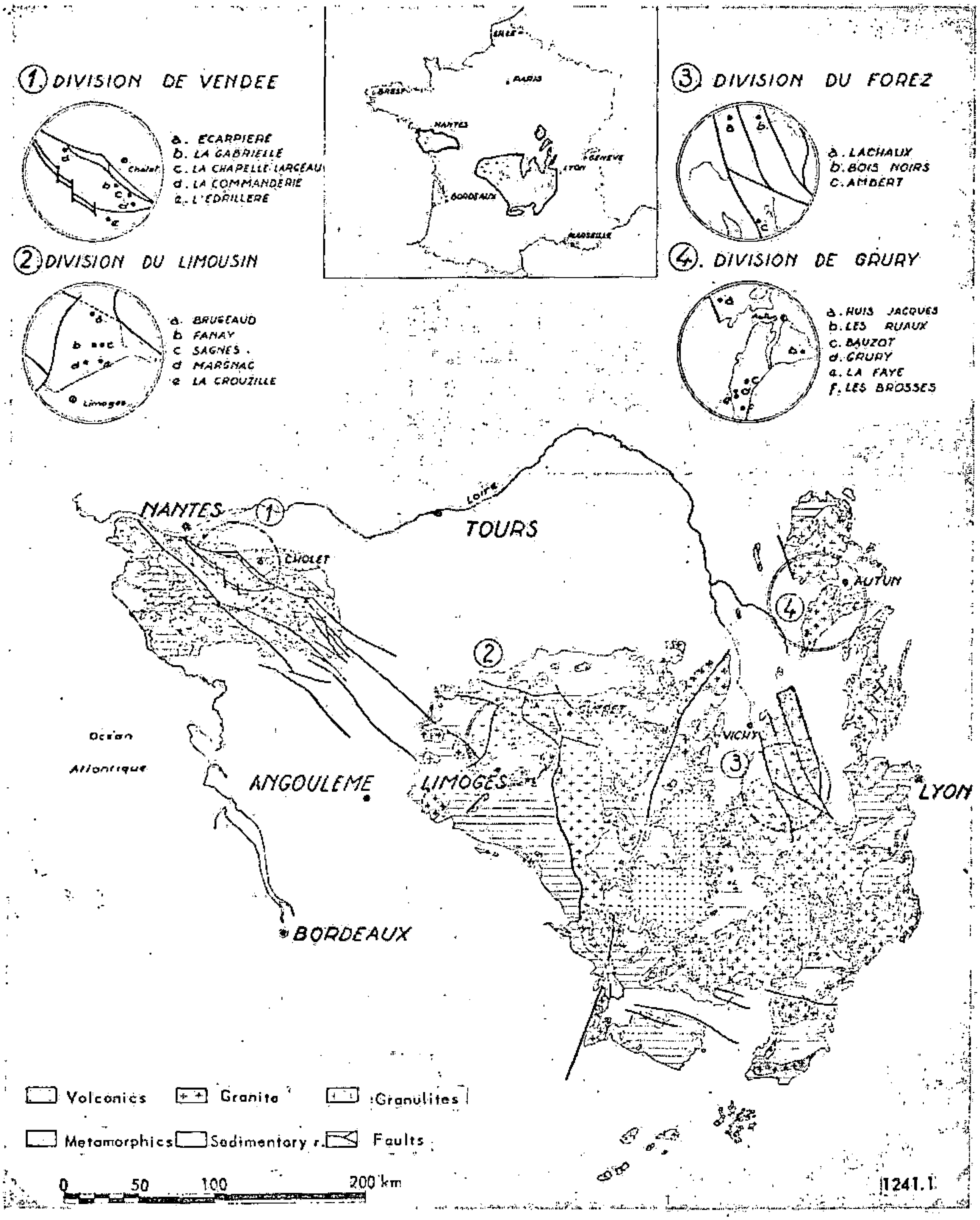


Figure 1. Mining divisions of the Commissariat à l'Energie Atomique of France

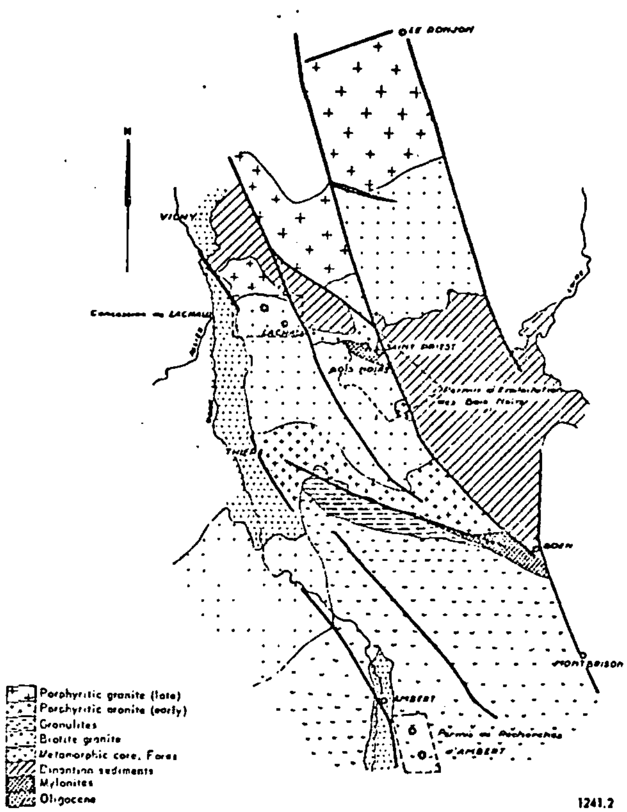


Figure 2. Division of Forez—Geology

The Bois Noirs lease contains mainly siliceous veins with pitchblende.

As for the Ambert region, it has numerous lenses of spherulitic pitchblende filling fractures in anatectic granite.

We shall describe a deposit representative of each of these types.

The Mineralized Districts

The Lachaux District—The Etang-de-Reliez Deposit

Explorations undertaken by the C.E.A. within the boundaries of the old Lachaux concession (Fig. 3) have shown that in all deposits to the west of the village uranium occurs essentially in parsonsite, accompanied sometimes by torbernite and autunite. Parsonsite, which was regarded as a rare mineral, is found here in rather large quantities in joints and in vugs in numerous smoky quartz veins; it is the principal and often the only constituent of the deposits containing several tens of tons of uranium metal.[2]

The country rock is a two-mica granulitic granite in which biotite greatly predominates over muscovite, except at the walls of uranium-bearing veins, where the reverse is true.

The most representative of these parsonsite deposits is the Etang-de-Reliez vein which we shall take as an example. It is a smoky quartz vein striking east-northeast which has been traced for 800 m and mined to the depth of 120 m. It dips 80° to the north and its thickness varies from 0.50 m to 2 m. The quartz is strongly fractured. Vugs are numerous, and the vein is cut by a series of north–south faults dipping to the east. The longest of these is no more than 70 m in length. This vein contains a variety of minerals. We have found the following:

(1) the *sulfides* sphalerite, pyrite, galena and chalcopyrite, with galena largely dominating but sometimes accompanied by chalcopyrite, by yellow sphalerite and very rarely by *purple fluorite:* in the crushed zones these sulfides are altered to pyromorphite, coronadite, cerussite and limonite; galena box-works are very common;

(2) *uranium mineralization consisting entirely of uranium phosphates*, pitchblende being absent even in the deeper levels; the nature of the phosphates, moreover, depends on the kind of sulfides present—parsonsite accompanies galena; torbernite, chalcopyrite; while autunite is found in those faults where sulfides are absent. Isotope analysis showed that parsonsite does not contain radiogenic lead; we have diagnosed these parsonsite deposits as ore bodies deposited near the surface by thermal waters carrying bicarbonate of uranium and circulating in the fractures of siliceous galena-bearing veins.

The Bois Noirs District

The Bois Noirs region, discovered in 1950 during an extensive exploration, lies to the southeast of Lachaux between the Sichon and Bresbe faults. It is a forested region, difficult to penetrate, which ends 1292 meters from Montoncel. The country rock here is mylonitized granite always strongly lineated, locally slightly granulitic and containing numerous aplite dikes.

There are many indications of uranium. They are distributed along three tectonic axes, two trending north-south and one north-west. They are due, in general, to deposits of little importance. However, the central axis contains in its northeastern part an exceptional accumulation of uranium minerals known

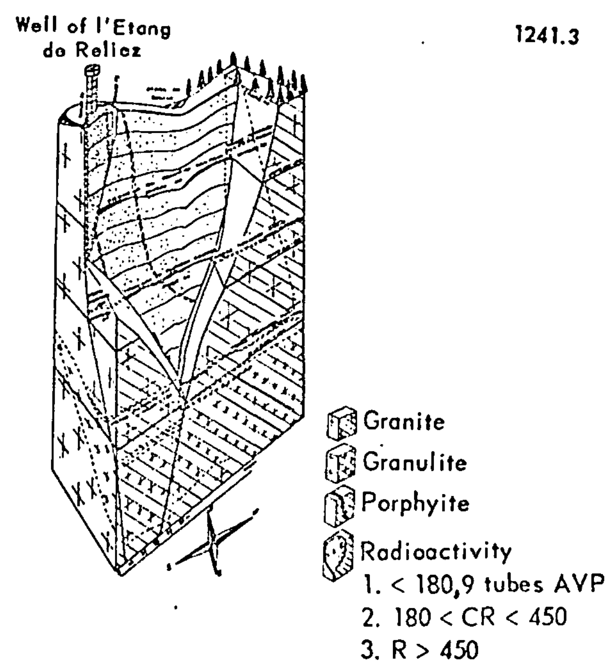


Figure 3. Deposit of l'Etang de Reliez

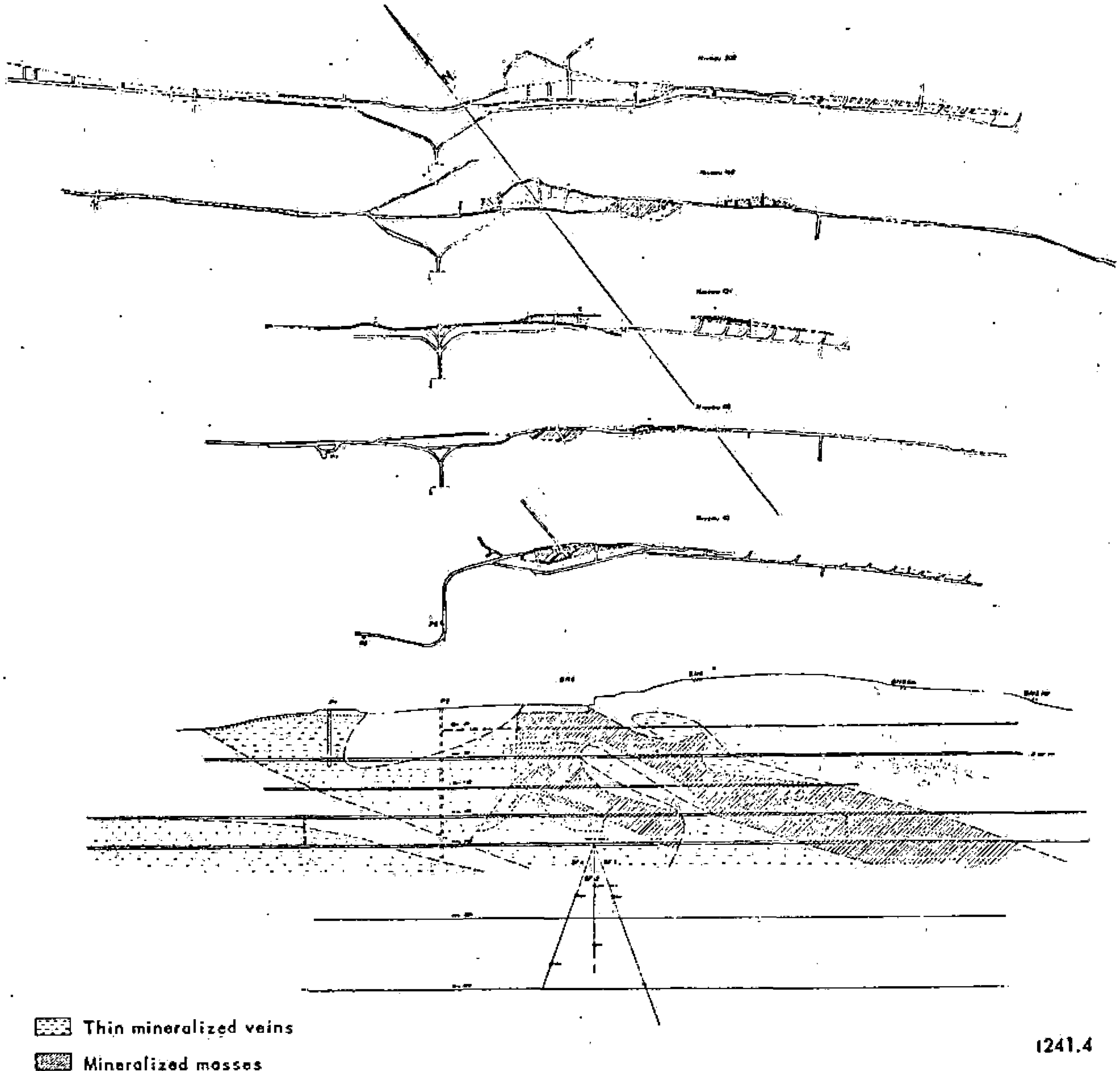


Figure 4. Deposit of Limouzat

as the Limouzat deposit (Fig. 4), which we have traced to the 200-m level and explored to the 400-m level by drilling.

From the structural point of view, it is necessary to distinguish between superficial and deep levels.

Superficial Levels.

The researches completed up to now delineate the structure of the deposit and permit study of the relations among the three blocks exposed at surface.

The most important part of the deposit is the central block BN5. It is a thick brecciated lens 150 meters long and 25 meters wide in the middle. It is bordered by two faults known as the roof fault and the wall fault.

The former strikes N 45° W, dips 72° NE and is represented by a broad band of gouge extending continuously along the roof of the lens through the three explored levels.

The latter strikes N 35° W, dips 65° NE and joins the roof fault at the northwestern extremity of the block.

The lens which is oriented northwest to southeast is sharply delimited by these two faults in its northwestern half. In its southeastern half, however, its wall is formed by the limit of silicification.

The central block consists of silicified aplite and contains strongly brecciated zones especially at the roof of the structure. The breccia and the fissures are enriched by quartz veinlets with pitchblende. The most highly mineralized zones are in the brecciated zone near the roof and in the east-west fractures which cut the silicified lens from wall to roof. The grade of these ore bodies ranges from 2% to 6%, depending on the level.

After brecciation, the mineralized zone was fractured and this gave rise to veins of nonuraniferous smoky quartz with sulfides.

The block BN6 is located to the southeast of the central block. It appears at the 40 m level in the form of an argillaceous zone 100 m long and with average width of 1.50 m coinciding with the roof fault, and contains black oxides and torbernite. Its average grade is 0.5%. Evidently this zone of black oxides is the thin upper termination of a large block. This block has been traced to the 80 m level, where it has the form of a lens 12 m thick in the middle terminating to the southeast in a single 2-meter vein; it extends along the roof fault and is composed, like the rest of the deposit, of siliceous breccia with pitchblende but of a much lower grade than the central block (0.2%).

The old mine is located to the northwest of the central block in the same position as the latter with respect to the roof fault which here becomes vertical. It is on a quartz vein with average width of 2.50 m and mineralized along the distance of 100 meters. The same structures are found here as in the central block, but here pitchblende is associated with more abundant quartz veinlets. It is more finely disseminated through the silica. It is often accompanied by galena. This association, galena-pitchblende, was not observed in the central block but it occurs in the neighboring deposit of Viaduc des Peux. The average grade of ore in the vein at level 80 is 0.5%.

Deep Levels

At the deeper levels the general structure of vein filling is preserved but with a number of important modifications which affect the three parts of the deposit.

The roof fault, defined above, changes direction and dip near the 120 m level. Its strike changes from N 50° W to N 30° W and its dip is sharply turned to the northeast. This change in structure causes a number of changes in the three deposits:

(1) the central block has a form which is the reverse of that at the surface—the two faults cut it toward the east; the roof fault, in branching from the wall fault, increases in width with depth, and this is accompanied by reduction in the number of east-west fissures joining these two faults and consequently by a decrease in "internal" mineralization of the ore body;

(2) the vertical vein of the old mine departs from the wall fault and becomes continuous along the entire deposit from the old mine to BN6, which is 10 meters to the southwest of the central block; at BN6 proper, these two veins become united and the vein filling is succeeded by a thick crushed zone produced by the roof and wall faults.

At depth, and this is confirmed by drilling to 400 m, the deposit appears to be reduced to three veins which spread toward the northeast and northwest over a distance of 1 km, so far as is known at present. Nevertheless, beneath the central block the three veins coexist but are too far away from one another to form a lode. The average grade of these veins is 0.2%. At times they are connected with one another by east-west veins analogous to those of the upper levels and probably the extensions of the latter at depth but with much reduced mineralization. To the southeast these veins have swellings up to 10 meters in thickness with a grade of 0.3%.

The principal uranium mineral is pitchblende. It is of concretionary type. It appears in spherulites, sometimes disseminated, sometimes in grouped fringes in the silica. It should be noted that the pitchblende is always accompanied by abundant silica called "rusty quartz". In the upper levels or along the faults numerous secondary uranium minerals occur: gummite, becquerelite, torbernite, autunite, ianthinite, and the black oxides. There are also many associated minerals such as galena, pyrite, marcasite, chalcopyrite, melnikovite, chalcocite and covellite.[3]

From the point of view of paragenesis, observations in the field and laboratory make it possible to distinguish four stages in the development of the Bois Noirs deposit:

(1) *crushing* of the granitic or aplitic zone with subsequent silicification of the fragments and sericitization of the feldspars;

(2) *uranium mineralization* proper which began with deposition of clear drusy quartz on the fragments of the breccia and sometimes on the veinlets of calcite; this quartz was followed immediately by pitchblende deposited usually in large spherulites, more than one millimeter in diameter; the deposition of pitchblende was followed by that of microcrystalline silica impregnated with hematite (hence, rusty quartz); this quartz undoubtedly altered the first deposit of pitchblende but it appears also that it, itself, was accompanied by formation of very small spherulites of pitchblende (1/100 mm) (in the uraniferous crust there is always pyrite, formed both before and after the deposition of pitchblende);

(3) *deposition of smoky quartz:* smoky quartz always cuts through pitchblende-bearing quartz and does not belong to the same stage of vein filling; it never contains pitchblende but carries chalcopyrite, pyrite, and very small amounts of galena; it contains also covellite, chalcocite and bornite, formed from chalcopyrite by supergene enrichment;

(4) *supergene alteration:* this is very prominent in the first 40 meters of the deposit and in the deeper parts in the vicinity of faults; in the oxidizing environment the supergene solutions produced colored minerals with hexavalent uranium, the main one being torbernite, while in the reducing environment they produced ianthinite, which was altered into "black products"; it is clear from this that the black products can be deposited far from pitchblende, for they do not necessarily form from its alteration in place.

We have seen that the Bois Noirs deposits are very different from those at Lachaux. They are typically hydrothermal deposits in which recent thermal activity does not appear to have played an important role. There is no parsonsite here, but pitchblende is very abundant and the secondary products are supergene. Moreover, in this region silica phases are numerous and well developed. We should note that there is always a clear-cut crushed zone between the red quartz with pitchblende and the smoky quartz.

The D'Ambert District

The deposits of this region are the last to be discovered in the Forez Division (Fig. 5). Unlike the deposits already described, those of Ambert are not in Hercynian granulites but in anatexite granites of the metamorphic complex. They are extremely heterogeneous biotite granites with numerous migmatite bands. In the area of uranium mineralization, as in the Lachaux concession,[4] these granites contain large amounts of muscovite.

The striking characteristic of this region is an extreme abundance of surface indications of pitchblende. We know thirty indications within the 24 km² area of the lease. Unfortunately, in most cases they lead to lenses which are not extensive either laterally or in depth. Among these, only two have given us hope of installing small workings: Bois des Fayes and Bois des Gardes.

The first of these is a fissure filling oriented northwest and having an average thickness of one meter. This structure was outlined by being traced for 80 m at level 40 and then by drilling to the depth of 120 m. It is a mineralized lens with pitchblende extending from level 20 to level 100.

Both mineralization and paragenesis are essentially the same here as in the Bois Noirs region. At present we can outline the following distribution of minerals: (1) pitchblende is found in masses of considerable size; its spherulites are 2 to 3 mm in diameter and very frequently form garlands always rich in pyrite; (2) silica, as in the Bois Noirs deposit, served to carry the pitchblende but it is much less developed here; (3) smoky quartz is present but not abundant; there is no crushed zone here, as at Bois Noirs, between the uraniferous veinlets and the deposits of smoky quartz, which is often molded on the pitchblende spherulites and cements the uraniferous channels.

In the second deposit, in Bois de Gardes, we found the same mineralogical and metallogenetic features as at Bois des Fayes. There is, however, an important structural difference. The first deposit does not show any signs of tectonic disturbance, while in the second, fissure veins merge into a fault zone produced by Alpine movements. The displacement broke the original vein and produced instead a stockworks of clay-filled fissures of greater extent. At the explored level (40 m on average), we found a siliceous breccia with pitchblende cemented by clay impregnated with black oxides. Drilling has shown that below the zone of alteration (about 100 m) mineralization is very irregular. Clay is devoid of black oxides and only the breccia fragments contain pitchblende.

THE GRURY MINING DIVISION (MORVAN)

The administrative and technical center of this division is at Grury (Saône and Loire) halfway between Moulins and Le Creusot. The first indications of radioactivity in this leased area were found in the vicinity of Grury.

Prospects extend from here to the northeast toward the region of Autun where autunite has been known for more than a century and a half and has been

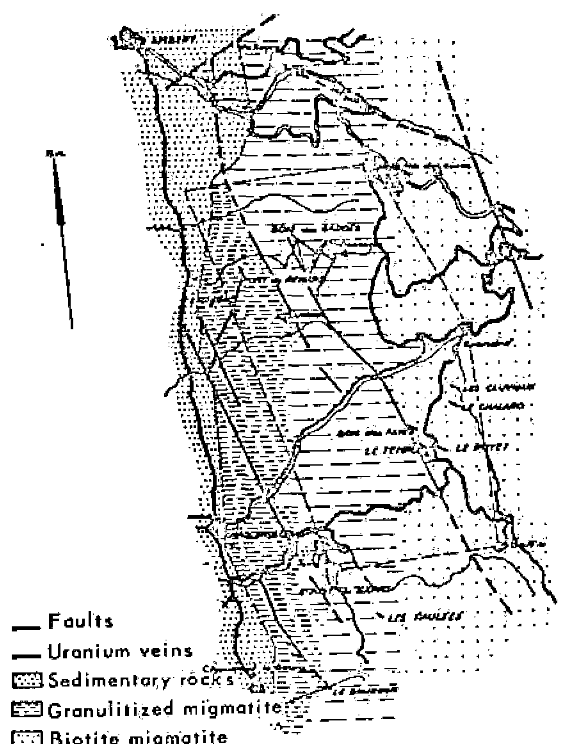


Figure 5. D'Ambert Region

mined on a small scale; and toward the north in the direction of Château-Chinon, i.e., practically over the entire crystalline terrain of the Morvan.

Geologic Setting

The main feature here is a horst of Paleozoic rocks bounded on the east and on the west by faults striking north-south, which separate it from the valley of the Loire in the west and of the Saône in the east.[5]

But although this horst is oriented north-south, it consists in reality of bands of volcanic and sedimentary rocks nearly all of which strike east-northeast as shown in Fig. 6.

The different bands consist of schists of undetermined age, basic volcanics interbedded with Devonian sedimentary rocks of the Dinantian series, Viséan granites, and post-Viséan granites which carry either biotite only or both biotite and muscovite.

The post-Viséan granites are potassic and of intrusive type. Locally they are traversed by lamprophyre dikes and contain xenoliths of schist. Uranium mineralization along favorable fissures was clearly influenced by this heterogeneity.

The Mineralized Districts

General exploration disclosed a number of mineralized areas which occupy either a central position in relation to the post-Viséan granites (Grury–Château-Chinon), or lie on the boundary between these granites and the schists (Saint Symphorien de Marmagné).

A recent exploration has shown, besides, the presence of strong concentrations of indications in the Permo-Carboniferous terrain along the north-south border of Morvan (the Blanzy basin). Their study is

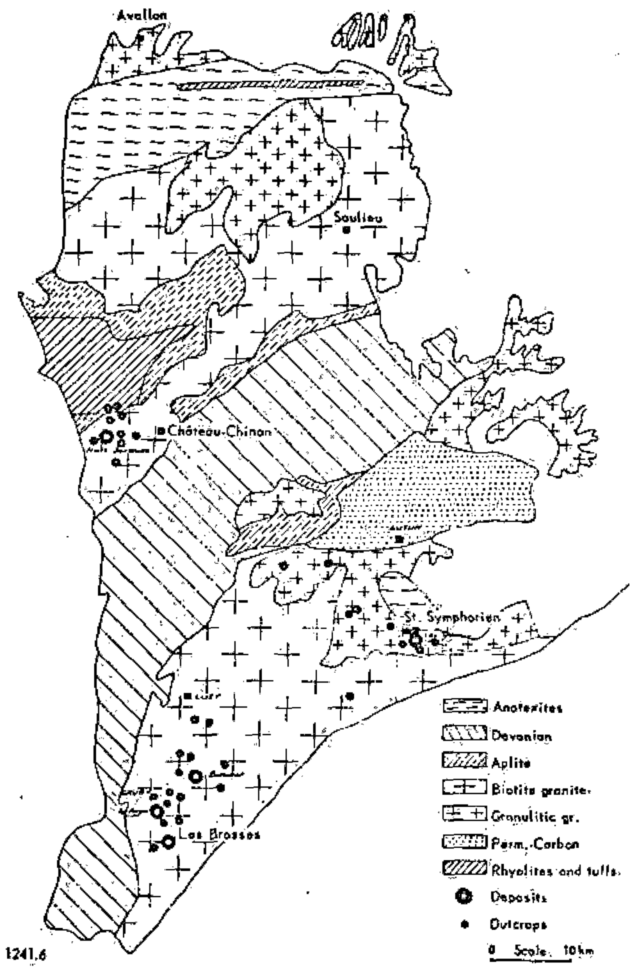


Figure 6. The Grury Division—Geology

not sufficiently advanced to be included in this work in which only the indications of the granitic Morvan will be considered.

General Characteristics

In Morvan more than anywhere else perhaps, the distribution of uranium mineralization in hydrothermal veins, or in association with these veins, presents subtle problems. Pitchblende is always distributed in an apparently irregular manner in the dislocated zones and the extent of mineralized blocks is always small.

Structure

Our study of the deposits revealed three types of structures.

(1) The *massive type* or mineralization in tension cracks. The pitchblende occupies numerous small cracks in the walls of great faults or near them; the fault zones are without gouge and often barren. Economic interest of such zones, which we call "massive" ore bodies, lies in the richness and abundance of the mineralized cracks which often form an extremely fine network and, accordingly, give rise to massive impregnation of the granite.

This type of deposit occurs at Ruaux near St. Symphorien de Marmagne.

(2) *The simple vein type.* Mineralization is confined entirely to a fissure which is usually quite wide (1 to 4 m) and was formed by relaxation of tectonic forces. Pitchblende is always accompanied by silica and fluorite, being distributed in the plane of the vein in lenses.

This distribution of pitchblende is due to variations in width and dip of the fissure.

A study made of the principal deposit of this type, that of Les Brosses near Grury, showed that the vein possesses (the plan of the vein being taken as a topographic surface) a veritable relief with ridges and saddles (Fig. 7), the former being especially favorable for the formation of mineralized lenses.

(3) *The mixed type.* In this type there appears to be a superimposition of the first two types: first, pitchblende was deposited in tension cracks during the stage of shearing, then, during the stage of relaxation, the principal fissures opened up, permitting formation of thick ore bodies either from a new supply of uranium-bearing solutions or from redistribution of the previously deposited material.

Deposits of this type are numerous in the Grury and Château-Chinon regions. The best examples are La Faye-l'Huis Jacques and Bauzot.

The first two are the most characteristic. In Figs. 8 and 9 it is possible to distinguish the massive ore bodies from veins or breccias, more or less siliceous and, clearly individualized. At l'Huis-Jacques a Tertiary re-opening occurred with redistribution of the old deposits in the unconsolidated gouge.

Bauzot presents similar features. Moreover, the distribution of mineralization was clearly influenced by the proximity of lamprophyres as shown in Fig. 10.

Mineralization

(1) *Uranium mineralization.* Uranium mineralization consists almost entirely of pitchblende. The mineral may be fresh or it may occur in a slightly altered condition in the crushed zone as a more or less pulverulent material commonly known as the "black product". In the larger bodies it is altered locally into gummite. Pitchblende is often absent from the superficial zones, having been removed by leaching; it may, however, be preserved in silica as a fine oolitic powder. There occurs also a series of oxidized minerals, with autunite being the most abundant.

The paragenesis differs in the different structural types described above.

The massive-type of ore contains practically nothing but pitchblende, either fresh and compact or crushed. Sulfides are rare here; but calcite is abundant in the zones with schist xenoliths. Furthermore, hematization is clearly developed in the mylonitic bands and along the vein walls.

In the simple vein and mixed types, mineralization is generally spectacular. The pitchblende, which occurs in large compact nodules or altered to gummite (Bauzot, Les Brosses), looks like powdered charcoal or black mud in the crushed zones. It occurs also as a fine powder together with sulfides in quartz, coloring the latter black or dark gray. Finally, in the poor

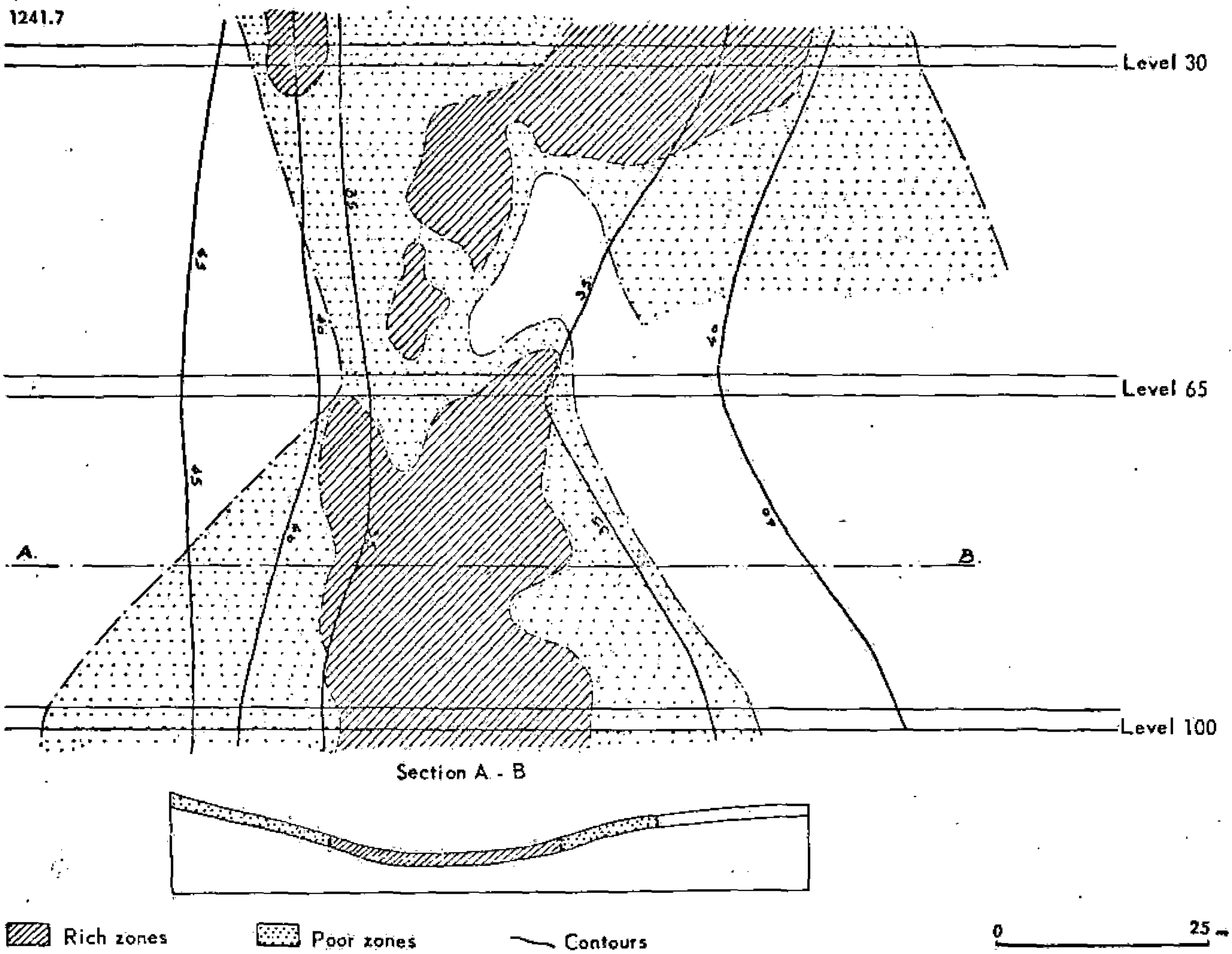


Figure 7. Des Brosses vein

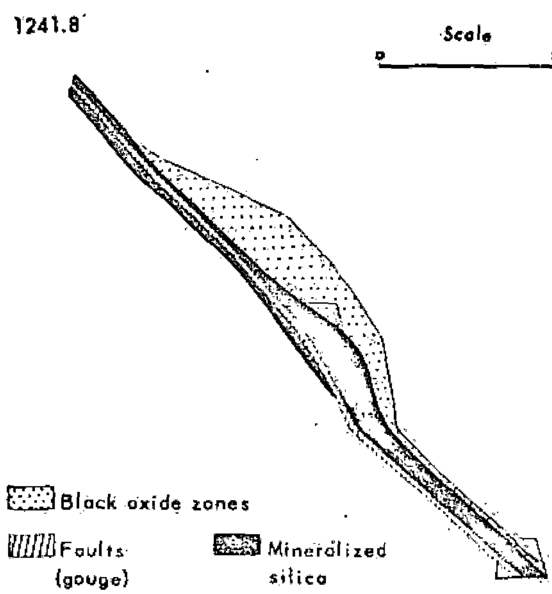


Figure 8. La Faye deposit

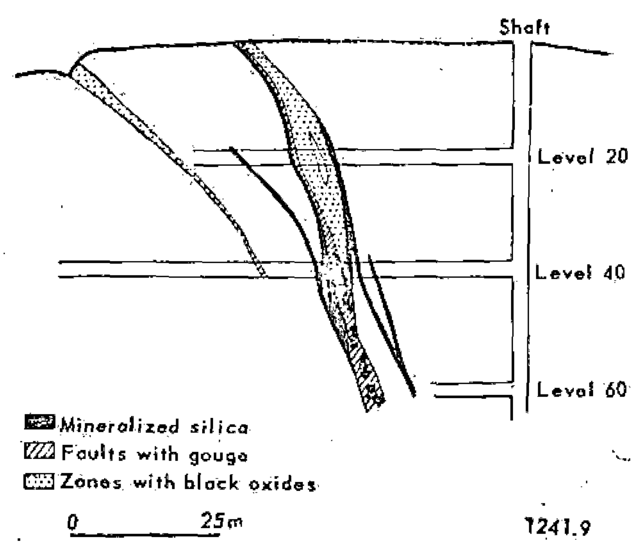


Figure 9. L'Huis-Jacques

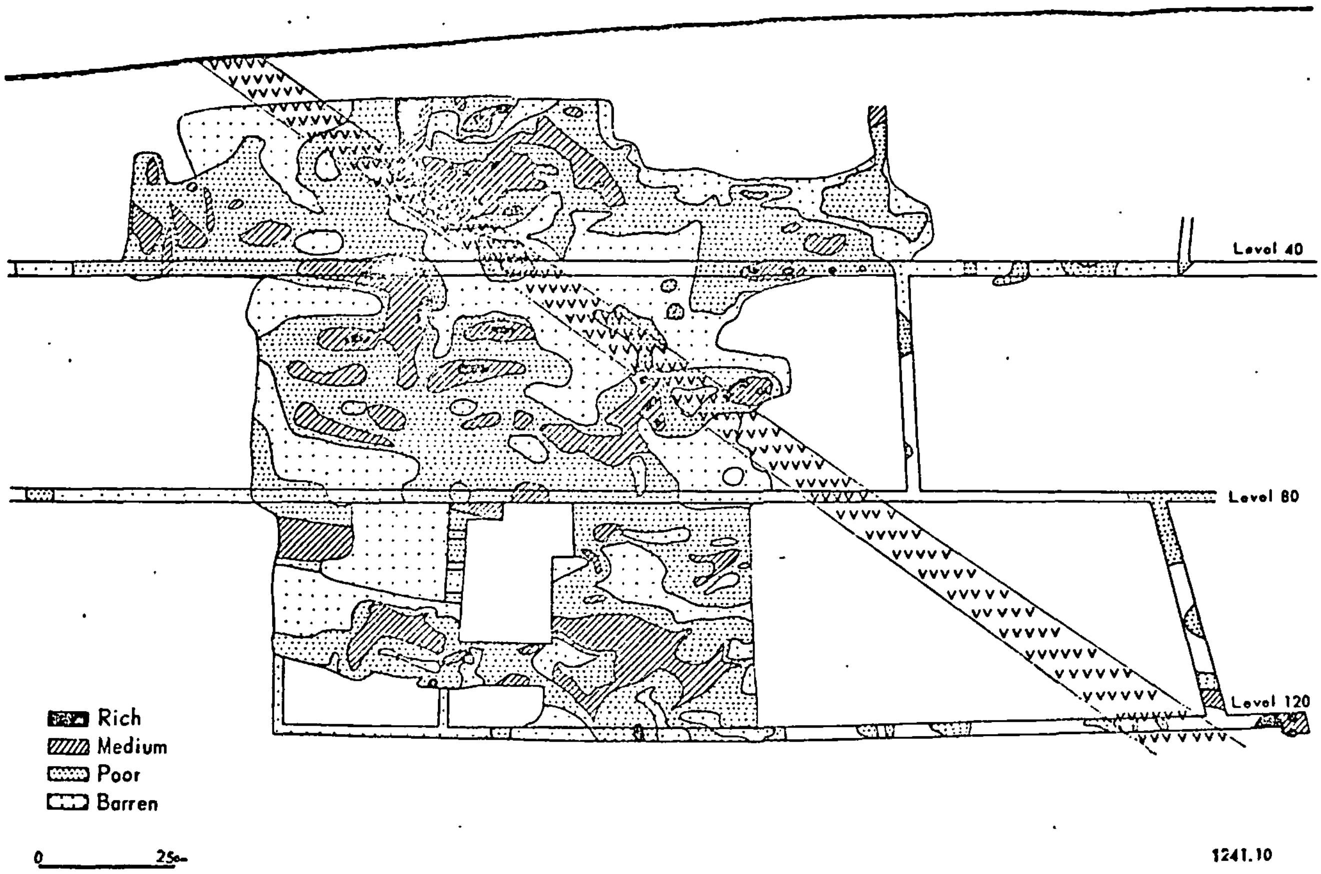


Figure 10. De Bauzot vein

argillaceous and siliceous ores, uranium, so far as it is visible, is present in the form of phosphates and silicates which have been described in the work by J. Chervet and G. Branche.[6]

(2) *Other constituents.* Chalcedonic silica is present everywhere. Very rare in the zone of massive ore, it forms, alone or with fluorite, the main filling of the thicker veins. Other gangue minerals are dolomite, calcite and barite.

Compact hematite sometimes occupies the axial zones of veins (Bauzot). Locally, in small particles, it invades silica and calcite. It is always present on vein walls impregnating the minerals of granite to a greater or less degree.

Among the sulfides, pyrite and marcasite are the most abundant, followed by galena, sphalerite, chalcopyrite and arsenopyrite.[7]

Paragenesis of the Uranium Deposits of Morvan

The uranium deposition phase was contemporaneous with compressive and shearing tectonic movements (late Hercynian).

The silica-fluorite phase coincided with the stage of relaxation of tectonism and the introduction of more uranium; deposition of great amounts of silica and fluorite followed this second uranium mineralization. This addition of materials resulted in rearrangement and dilution of the older mineralization. Deposition of sulfides was a part of this phase, which is either late Hercynian or early Mesozoic.

The recent phase of argillic alteration, contemporaneous with Alpine movements, brought no additional mineralization but affected most of the deposits and especially the thicker ones.

LA CROUZILLE MINING DIVISION (NORTHERN LIMOUSIN)

The administrative and technical center of this Division is at Razès on national highway 20, 25 km to the north of Limoges. It is named after the first pitchblende locality discovered in 1948 not far from La Crouzille pond. This locality was immediately exploited by the Henriette Mine, which was closed after reaching the depth of 235 m. This mine has been repeatedly described.[8, 9]

The deposits and indications of mineralization are spread over an area of about 320 km^2, which has not yet been completely explored.

Geologic Setting

The granulitic massif of Haute-Vienne (Fig. 11), the center of which contains the mining leases, may be regarded as being formed by the confluence of the Hercynian granulitic chains of Millevaches and those of the Marche, to the west of the granite-gneiss dome known as the plateau of Guéret.

To the south and southeast, the granulite is roughly concordant with mica schists and gneisses. To the north, it passes into the contemporaneous granulites of the Marche which bend around the granite-gneiss massif of Magnac-Laval and disappear under a sedimentary cover of Poitou.

In the east the Arrènes fault, which continues to the north, separates them from the granite of Guéret.

In the west, a similar fault trending north to north-northeast separates them from the granite-gneiss massif of Magnac-Laval and the small granite-granulite massif of Blond.

To the reader of the recent general works [10, 11] and of the detailed accounts by geologists and prospectors of the Division, the granulitic massif of Haute-Vienne appears as follows:

Petrography

From northwest to southeast one passes gradually from the clearly lineated symmetamorphic granite with biotite, anorthoclase and oligoclase, known as the Brame granite, into a granulite with dominant muscovite, biotite, microcline-perthite and plagioclases very near albite, homogeneous as a whole and devoid of lineation, called Monts d'Ambazac granulite (Fig. 12).

Granite and granulite are cut by fine-grained rocks with a characteristic texture, carrying either muscovite only, or muscovite and biotite, which we have grouped under the name of granulitic granites and late granulites. These "intrusives", which are richer in soda than the two-mica granulite, occur in very gently dipping dikes and lenses in a pattern which recalls the surface joint pattern of a crystalline massif; at depth they appear to "spread roots" in the two-mica granulite.

Zones bordered by alkalic "episyenite" can be distinguished in this complex; the change from the enclosing rocks is gradual yet rapid, quartz and muscovite disappear, biotite is replaced by chloritic aggregates and sometimes by secondary biotite rich in accessory apatite and zircon, and the entire rock mass is impregnated with hematite.

There is also a series of pegmatites related to the granulites and ranging from common potash pegmatites with apatite and beryl to soda-lithia pegmatites. The former are found especially to the north and northwest of the Ambazac Mountains within the masses of vaguely lineated intra-granulite which becomes more and more differentiated southward. The latter occur only to the south of the mountains; they are vein-like and cut the contact between granulite and the gneiss-mica schist complex.

Finally, there are dike rocks, aplites of the same composition as the two-mica granulite and lamprophyres with dominant biotite and augite (minette).

It should be noted that the changes in the granulite complex with increasing distance from the Brame granite are marked: [12]

(1) by progressive elimination of iron, most of which is concentrated in the lamprophyres;

(2) by greater and greater enrichment in soda (it is in the lamprophyres again that potash and lime become concentrated);

(3) by intense sericitization (the last micas to crystallize are no longer muscovite but light-green micas in tufts and epigenetic aggregates of the same type as the late gilbertite of the pegmatites);

(4) by regional kaolinization of granulite, a well-known phenomenon which it is useful to recall.[13]

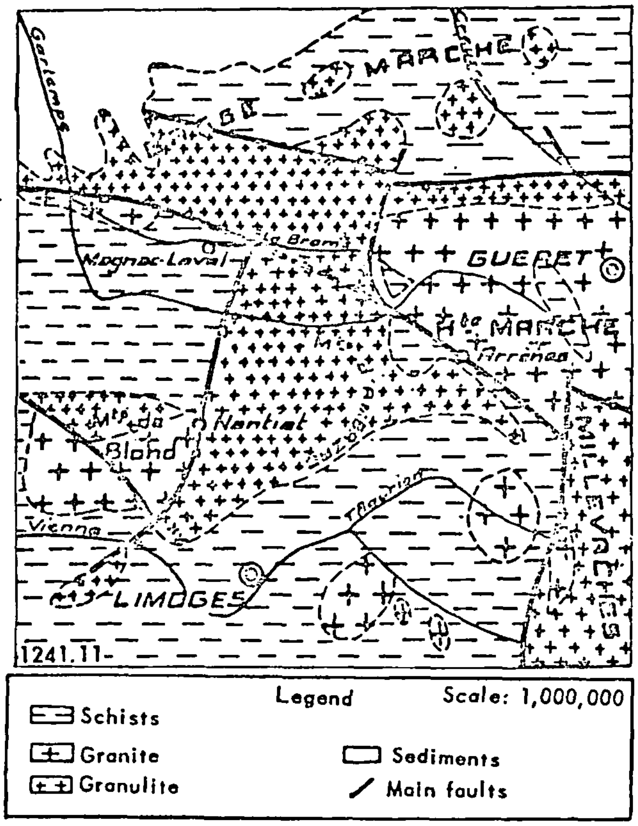


Figure 11. Northwestern part of Massif Central—Structures

To complete the description of the region we should mention the indications of tungsten and gold occurring in the aureole of the granite massif.[14]

A small massif of porphyritic biotite granite adjoins the granulite to the west of Ambazac. It is perfectly homogeneous and completely devoid of veins. Although difficult to date, it appears to be younger than the granulite complex, but it is cut by the soda-lithia pegmatites.[12]

Structure

The Brame granite and to a much less degree the two-mica granulite have a noticeable trend north-south and north-northeast as far as the Gartempe River; beyond it the trend changes to the northwest and continues in the west-northwest ranges of Marche.

The granulitic granites and the late granulites are aligned north-south and then northeast toward Marche.

The potash pegmatites occur in chains whose general trend also appears to be north-south.

The syenitized zones trend north-south and north-east-southwest.

The dikes of aplite, lamprophyre and soda-lithia permatites are oriented to the northeast as a whole; their dips are always steep but have a tendency to become gentle at depth.

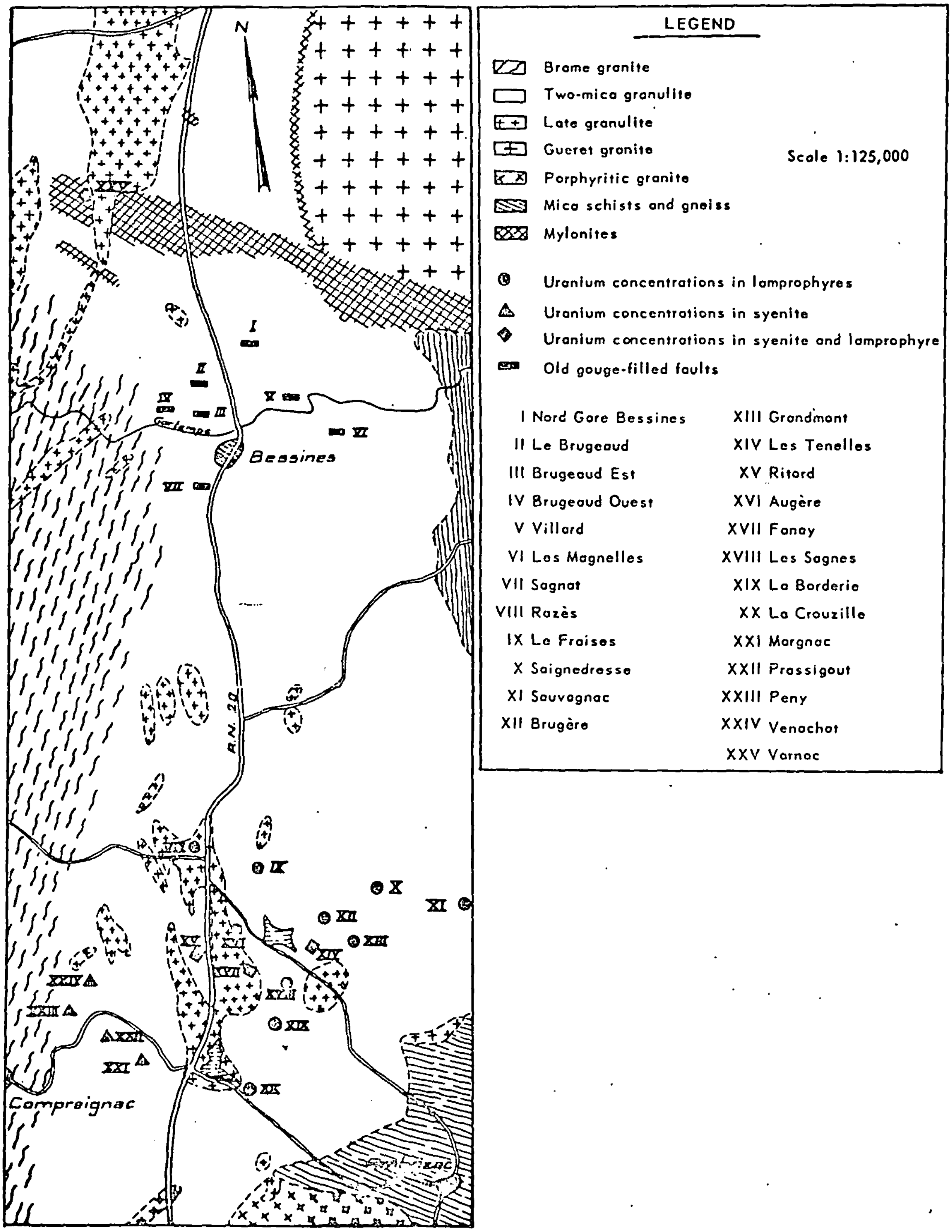


Figure 12. Uranium deposits and outcrops

The mylonites oriented west-northwest, roughly parallel the extensive mylonitic system of Marche which cuts across the massifs. They are slightly displaced by the north-south and north-northeast faults of the same type as the Nantiat fault; they are crossed without dislocation by the late granulites, aplites and lamprophyres. The largest among them are a continuation of the Arrènes dislocated zone and trend in the direction of the fault of that system which cuts granulite to the north of Magnac-Laval; there are many other faults which cannot be shown on the scale of Fig. 12. These cataclastic zones are very old but have certainly been rejuvenated time and again, and it is in the later fissures with steep dips, usually to the south, that uranium mineralization was concentrated under conditions which will be discussed later. No important movement has occurred since the deposition of uranium ore, i.e., since early or middle Jurassic according to the ages determined on pitchblende, but rejuvenations of the old fracture systems on a small scale have occurred frequently.

Uranium Concentrations

General Characteristics

The characteristics of the uranium deposits of northern Limousin are:

(1) simplicity of mineral association; pitchblende, the dominant mineral, is accompanied by iron sulfides, pyrite, marcasite and melnikovite, while other sulfides, galena and bismuthinite are scarce; the gangue is not abundant and may be absent altogether; it consists of chalcedonic silica contemporaneous with pitchblende and fluorite, var. antozonite, which fills the remaining parts of veins; light-colored barite is at times found under the same conditions; calcite always appears in the most strongly crushed parts of the granulite and is the latest of the gangue minerals;

(2) small-scale structural complexity of the mineralized zones which, being hardly cemented with gangue, are susceptible to alteration: Limousin ore bodies frequently contain deposits of the "black products"—crushed pitchblende and other black uranium minerals of the zone of secondary enrichment, and large "uranium gossans" consisting of "yellow products" but showing little variety, barite-bearing autunite and silicates being the main minerals.

Concentrations occur:

(1) in fractures, actually old joints reopened at the contact with lamprophyres, as in the case of the main vein at the Henriette Mine, which extends 250 m in depth, or in the deposits at Les Sagnes, which are of the same type but with a more complex fracture system;

(2) in networks of fractures and faults which expand at the contact with syenitized masses and contain large richly mineralized lenses at Margnac;

(3) in secondary fractures and faults, related as a whole to the old north-south faults and located in the zones where granulite had irregularly assimilated relatively large amounts or iron-rich metamorphics, as in the case of Les Brugeauds deposit and the adjacent mineralized localities where granulite is constricted between the Brame granite and mica schists.

All mineralized zones are marked by a greater or less development of hematite in the enclosing rocks except in the unusual case of the Henriette type of vein, which remained intact after mineralization. The least alteration of pitchblende is accompanied by the reddening of the gangue and vein walls due, in part at least, to the oxidation of pyrite.

All concentrations of types 2 and 3, and some similar to type 1, result not from a quiet filling of open joints but from impregnation of fault zones coinciding with the zones of hematite, which were already in existence at the time of deposition of pitchblende and the sulfides, since these minerals are perfectly fresh and without the slightest trace of oxidation. The more or less abundant calcite is the main gangue in these deposits.

It appears that the formation of hematite related to the pitchblende deposits, of whatever origin,[15] is always much older than they are and is the result of an early alteration of biotite occurring during the process of syenitization and granulitization of rocks relatively rich in iron. Iron was freed at this time and hematite completely impregnated the syenites as well as the plagioclases of the granulite, and at this time also biotite was destroyed and replaced by muscovite.

Principal Deposits and Outcrops

A paper read at this conference described in detail the three principal deposits of northern Limousin.[16] The Henriette Mine has also been described in detail.[9] We shall limit ourselves here to a very brief account of these deposits.

Figure 12 shows location of deposits and outcrops in La Crouzille Mining Division which have already been explored to a certain extent; it indicates also the type of concentration represented by each of these. These types will be described below.

Uranium Concentrations on Lamprophyres

The "Henriette column" (Fig. 13) whose exploitation has stopped, furnished some 150 tons of uranium metal from an ore of a very high grade; this thin and narrow lentil with a lamprophyre dike as its axis extends to the depth of 250 m, where it ramifies through a thick system of fractures and becomes unworkable.

Other veins of less importance occur under identical conditions on the neighboring lamprophyre dikes.

The characteristics of this type of deposit are:

(1) an exceptional sharpness of the mineralized fissure and its persistence; there is no mineralization a few centimeters away from the vein and very little of the "black products";

(2) an abundance of iron sulfides which constitute at least 50% by volume of the mineralized material;

(3) smallness of cross sections of the lentils, which are proportional to the thicknesses of the lamprophyre dikes; a lentil 2 to 8 cm thick is associated in La

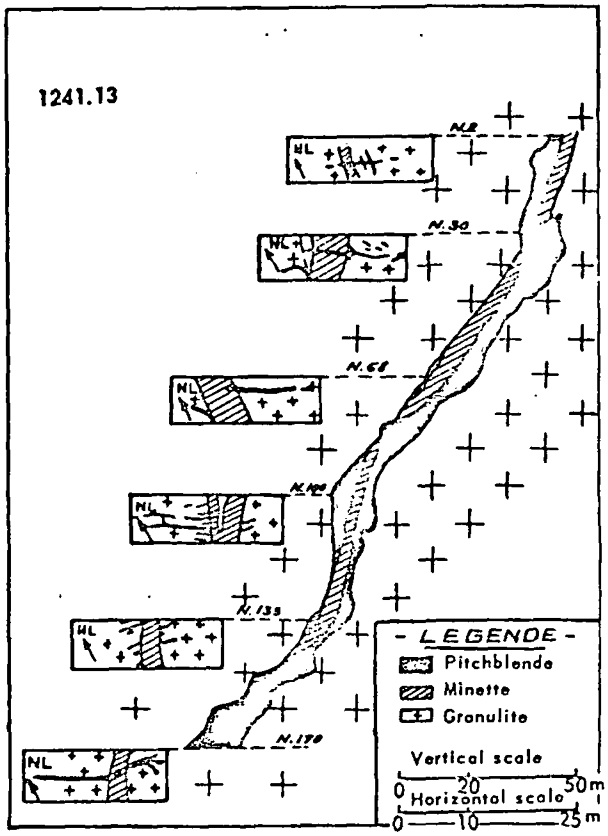


Figure 13. La Crouzille-Henriette deposit—Henriette column

Crouzille-Henriette deposit with a minette dike 3 to 6 m thick; veinlets a few millimeters thick are associated with minette dikes about one meter in thickness; lengths in plan range from 1 to 15 meters;

(4) finally, hematite on vein walls and in the gangue is developed very weakly or not at all in these deposits; it is a product due to rejuvenation of the mineralized fissures; on the contrary, the faults which cut minette dikes show very strong development of hematite; here, pitchblende was deposited with a small amount of sulfides and with calcite, which is also partly impregnated with hematite.

In the same group of lamprophyre dikes which contains the Henriette deposit, there are almost identical deposits at La Borderie and Brugères.

Other dike systems contain the poorly known deposits of Grandmont, Saignedresse and Sauvagnat.

The deposit of Les Sagnes (Fig. 14) is also a concentration on a minette dike but the mineralized fractures are much more extensive and complex; they form a network within granulite and in a thick aplite dike where they are not enriched; the dike must have played a purely mechanical role in formation of the deposit.

Pitchblende is accompanied here by chalcedonic silica, and has been altered to "black products" either during a reopening of the fissures or during deposition of purple fluorite-antozonite. The mineralization is largely disseminated through the neighboring fissures and the deposit does not have choice concentrations; it is of low grade.

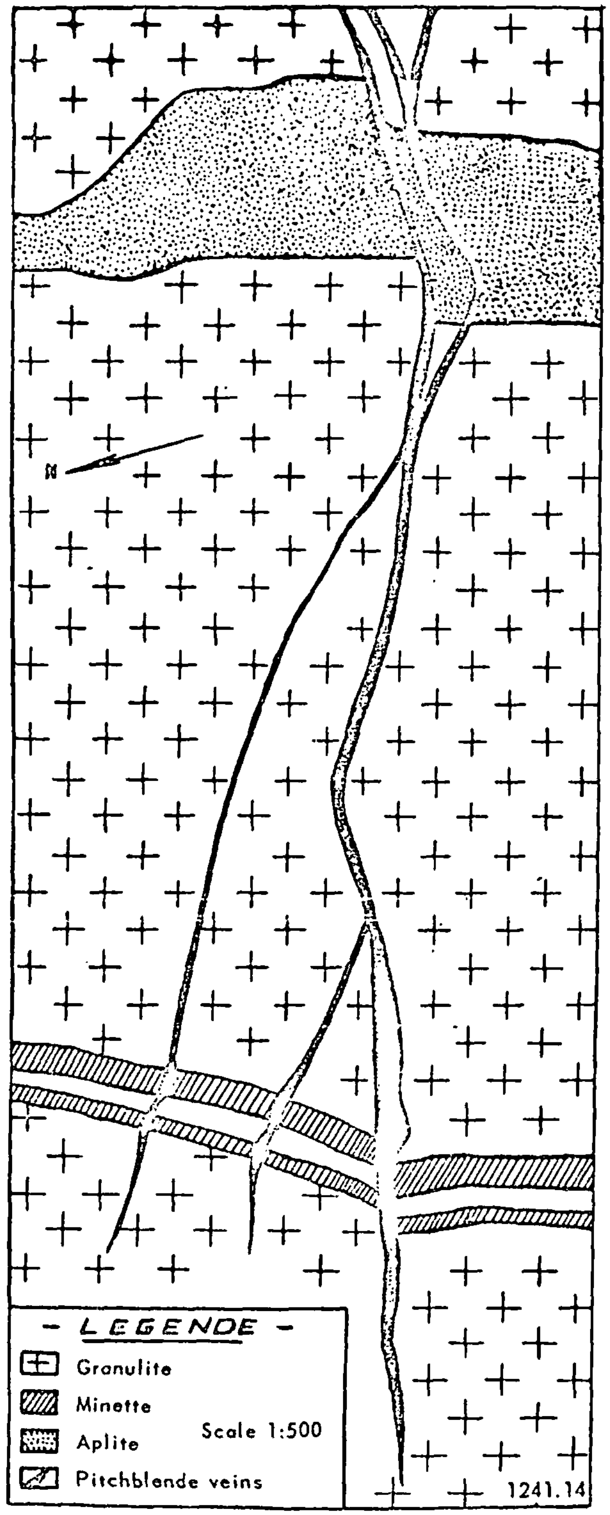


Figure 14. Les Sagnes deposit, level 80-main vein

The Augères deposit, altered during a tectonic phase which caused deposition of "black products" in a north-south fault at the expense of the primary vein pitchblende, also has a minette dike for its axis. The same is undoubtedly true of the Razès deposit.

The Fanay deposits, the Ritord and the Tenelle, on the same fracture zone as those of Les Sagnes, are similar concentrations of pitchblende on lamprophyres

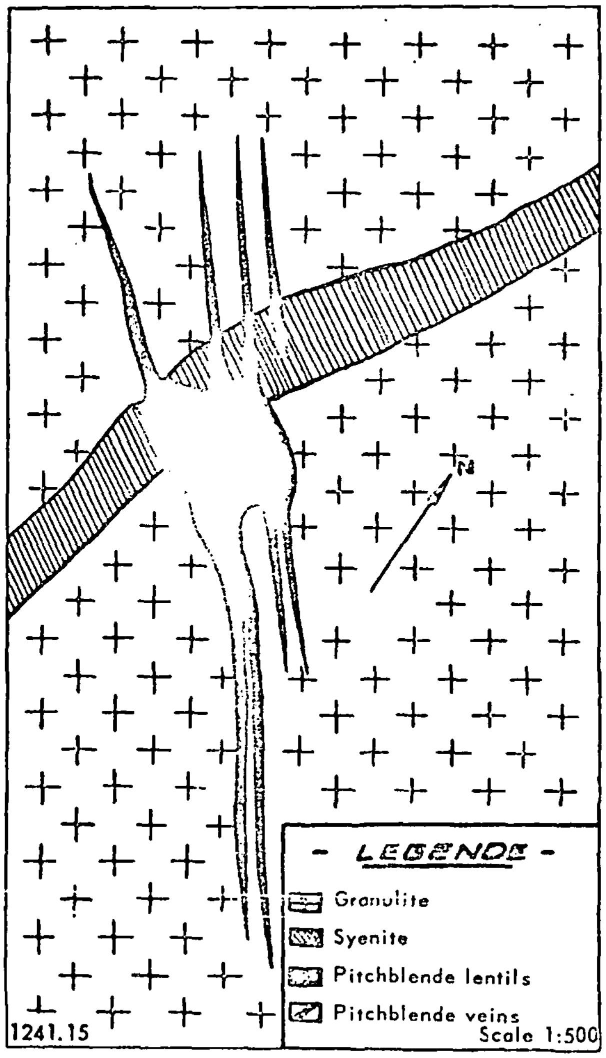


Figure 15. The Margnac deposit, level 115, principal lentil

and also on syenitized zones; alteration is slight in this group.

Uranium Concentrations in the Syenitized Zones

The deposits at Margnac (Fig. 15) and their continuation in the outcrops of Pény, Prassigout and Vénachat are of this type.

They contain thin veinlets of ordinary pitchblende which may extend for hundreds of meters from the enormous lenses of pitchblende concentrated in the syenites. One of these lenses measured 12 m in length, 12 m in height and 4 m in width, with an average uranium content of 15%.

The characteristic features of this type of deposit are:

(1) intensive development of hematite, undoubtedly largely antedating the deposition of pitchblende;

(2) scarcity of sulfides, galena being especially rare;

(3) carbonate gangue;

(4) frequency of structural changes on a small scale accompanied by dissemination of a part of the pitchblende in the form of various "black products" in the vicinity of the primary deposit with consequent impoverishment of the latter; a "uranium gossan" usually appears on the surface containing especially rich concentrations of secondary uranium minerals.

Concentration in fractures and faults related to the old dislocations and in the zones of intensive and heterogeneous granulitization. (Zone of endomorphism of granulite.)

The Brugeaud deposits (Brugeaud-Est, Fig. 16, and Brugeaud-Ouest), the deposits of Magnelles and Villard, of the Bessines Station and of Sagnat are of this type.

The old faults trending roughly north-south are either large gouge-filled faults (up to 5 m at Brugeaud-Est) or zones of tension in the granulitized complex where faults and fractures are not visible but are revealed perfectly by resistivity measurements; this is the case at Brugeaud-Ouest where the zone with the lowest resistivity corresponds to an elongated islet of residual irregularly granulitized fragments of gneiss which can be interpreted as "hollow" in the regional front of granulitization.

The characteristics of these deposits are:

(1) the irregularity of veins and their complexity;

(2) the exact juxtaposition of pitchblende mineralization and the development of hematite, the mineralization occurring in well-individualized massive veins with thin hematite fringes, or in intricate nets of reddened fissures and faults in the mass of granulite;

(3) the frequent occurrence of alteration and diffusion of pitchblende in the form of "black products" below the topmost levels into the neighboring fissures: this gives the impression of massive ore bodies in the strongly fissured zones which in the case of Brugeaud-Est, for example, are those of the most intensive faulting.

At Villard, quartz gangue is abundant and its deposition was terminated by the appearance of smoky quartz and purple fluorite which seal certain

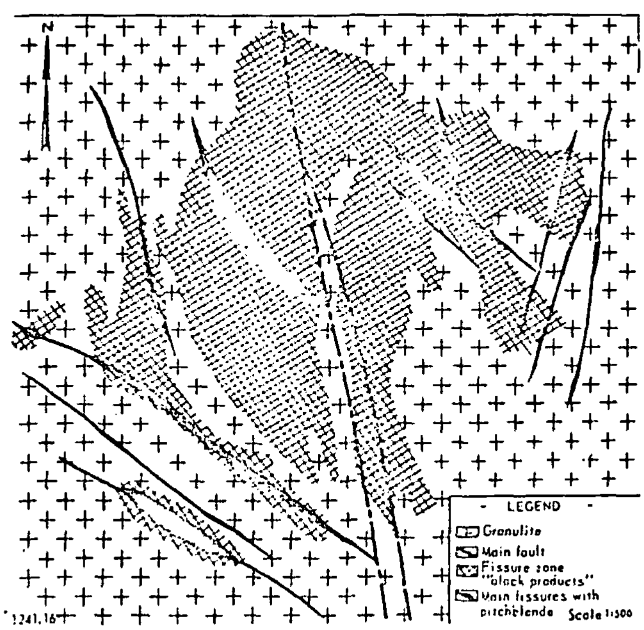


Figure 16. Les Brugeauds deposit, level 65, northern body

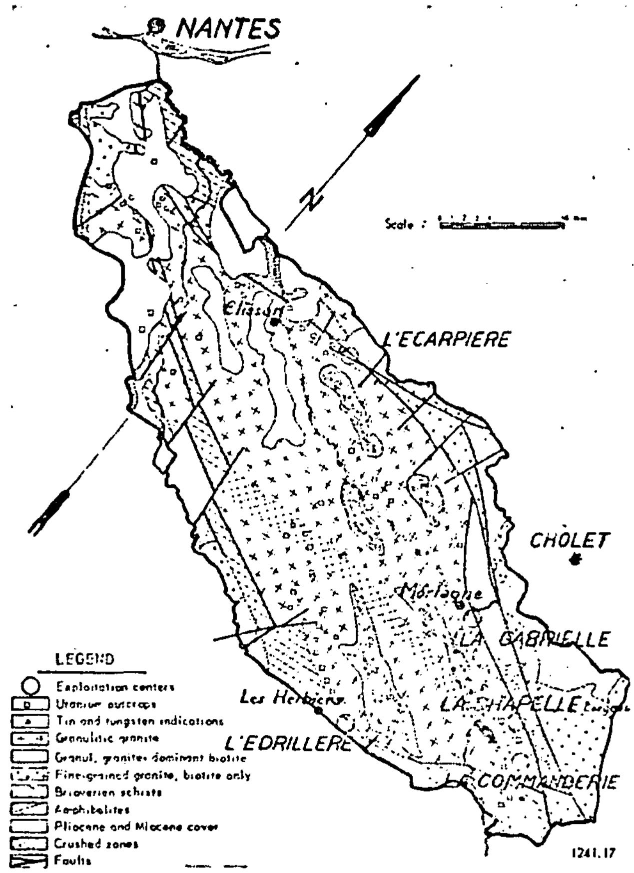


Figure 17. Vendée mining division—Geology

subordinate fissures in the large crushed zone some kilometers to the north and contain a number of secondary uranium minerals such as autunite and torbernite.

The rest of the deposits are not well known.

THE VENDÉE MINING DIVISION (BAS-POITOU)

The administrative and technical center of this Division is at Mortagnes-sur-Sèvres about 60 kilometers to the southeast of Nantes. Exploration covered the entire crystalline massif of Vendée, which is the southeastern prolongation of the Hercynian massif of Brittany, uniting it with the Massif Central under the sedimentary cover of Poitou.

Geologic Setting

The uranium deposits of Bas-Poitou lie in the central part of the complex known as the Paleozoic Massif of Vendée.[17] This quadrilateral, well defined on 1/M maps, is conventionally bounded on the north by the Loire, by the Atlantic coast on the west and on the east and south by the Paris and Aquitania sedimentary basins. It covers an area of about 12,000 km^2 between the western arc of the Armorican Massif and the granites of Marche, and is separated from these by the Lower Jurassic transgression known as the Strait of Poitou. This area has no geographic unity. The axis of relief lies in the Gatine hills trending northwest, whose elevation does not exceed 200 m and becomes gradually lower toward the sea. The structures result from two tectonic trends, the principal one, oriented to the northwest, being cut and sheared by north-south flexures. A Pre-Cambrian fold in ancient metamorphics known as the Cornouailles anticline trends northwest and continues through the entire central Brittany. It is bordered by two synclines of Cambrian to Upper Devonian age filled with mica schists, the Plaine Vendée syncline in the south and the Mauges and Gatine syncline in the north. Each of these downwarps is pierced by Post-Carboniferous intrusive granites with which uranium is intimately associated, especially in the north. There, granulitic granites form a discontinuous ridge with its axis passing through Nantes–Glisson–Mortagne–Bressuire–Parthenay. Uranium outcrops surround the Mortagne batholith and extend in a band for 75 km from Bressuire to Nantes with the greatest width, 19 km, between Cholet and Herbiers (Fig. 17).

Uranium Deposits

General Characteristics

The principal deposits discovered at the end of 1951 [18, 19] lie on the northern border of the granulite and are associated with much-faulted mylonites dipping to the northeast. Three examples will be described; they are from west to east: L'Escarpière, La Gabrielle and La Chapelle-Largeau.

Others, such as Commanderie, are in the north-south fissures at the eastern extremity of the batholith.

Still others, such as l'Edrillère, mark the southern and southwestern borders of the massif and lie either at the contact or within the granite.

All these deposits have characteristics in common which it will be convenient to enumerate before describing their distinctive features:

(1) outcrops are rare because of abundant vegetation;

(2) oxidized zones are shallow and contain autunite and gummite passing at the depth of 10 meters into pitchblende with its secondary " black products ".

(3) pyrite is always associated with pitchblende, and melnikovite with the " black products ";

(4) pitchblende is always associated with the breccias;

(5) sulfides and other ores occur only in microscopic traces;

(6) the system of mineralized formations continues to the southwest;

(7) there is a disparity in the orientation of structures; the irregular fissures with sharply defined edges and containing sporadic deposits of pitchblende alone trend north-south, while compressed, altered fissure veins with pitchblende dispersed in the gangue and frequently accompanied by the " black products " trend to the northwest.

The deposits of Vendée appear to lie along the faulted borders of a Post-Carboniferous granulitic granite batholith. Determinations of age on the pitchblende have shown that all deposits are contemporaneous but the inexactness of these determinations does not permit assignment of an absolute age. Regional

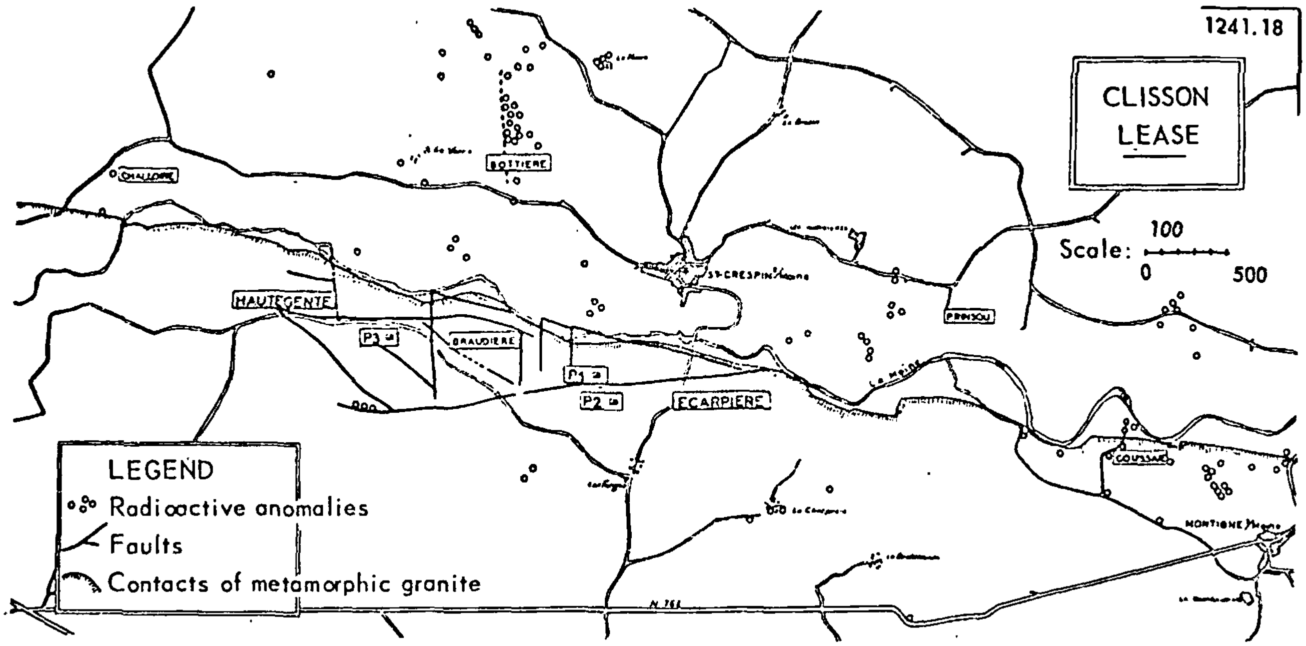


Figure 18. L'Escarpière deposit

geologic studies indicate that it may be Lower Jurassic or Triassic, which corresponds to the ages of most French uranium deposits. It is interesting to note that the interior of the batholith is occupied by a strongly radioactive fine-grained granite which, as its geology indicates, must be residual of endomorphism. No uranium mineralization has been found in it, but tungsten, tin and copper have been found on its periphery.[20] Uranium, possibly, forms a second aureole, but this is merely a hypothesis. A geochemical study is now in progress which will undoubtedly give a definite answer to the question of the origin of these deposits.

Principal Deposits and Outcrops

At L'Escarpière[21] near Clisson, uranium occurs in an area of intensive fracturing several tens of meters from an abnormal contact between granulite and amphibole schist (Fig. 18). A powerful thrust from the southwest fractured and profoundly metamorphosed the original rock. It was mylonitized parallel to the border and in flexures deprived of its quartz and biotite, becoming a red episyenite. Uranium is associated with numerous anastomosed fissures and is enriched at their convergences. It occurs either as fine-grained pitchblende in silica-fluorite gangue in bundles of thin veinlets or, in the more strongly crushed zones, as pitchblende associated with "black products" and red chalcedony; here the veinlets ramify in all directions and the intensity of fracturing resulted in a free circulation of water, causing leaching out of fluorite and the development of kaolinitic clays as well as of pulverulent "black products". Ore of the greatest economic importance appears to be related to the convergence of the fissures and occurs in fusiform masses attaining 10 meters in width and 200 meters in length. In this mass the rock has been altered from granite by way of numerous successive fractures, and now presents a network of veinlets filled with silica and fluorite (purple fluorite or antozonite). The density of these veinlets makes the mass workable and the larger openings in it contain fine concentrations of massive pitchblende lying between quartz and fluorite. These special zones are the "soul" of the mass, with grades decreasing progressively toward the borders by the thinning out and increasing spacing of the mineralized veinlets.

The deposits extend for two kilometers from east to west, and have been exposed by mining operations and drilling to the depth of 200 meters.

The Gabrielle deposit, near Mortagne, is composed of lentils with pitchblende and "black products" winding along the contact between silicified granulite and schist breccias. The breccias form a band trending N 10° W and for about a hundred meters follow an outlier of granite.

The breccia which serves as the gangue for pitchblende is entirely granulitic and is cut by veinlets of pyrite and microcrystalline quartz accompanied by iron hydroxides which are molded on its fragments. The pitchblende occurs as impregnations in the silicified rock and in masses in shrinkage cracks. It appears to have been deposited directly in the gangue by metasomatic replacement of the feldspars.

Mining operations, started recently, have already traced two pitchblende lenses, and a search for others is being made. It should be noted that four points in a clayey prairie, each isolated by three faults, and associated with siliceous debris with autunite were the beginnings of this mine.

At the Chapelle Largeau (Fig. 19) near Châtillon-sur-Sèvres, pitchblende was deposited in two veins 100 meters from the contact between granulites and schists; the larger of the two veins, called

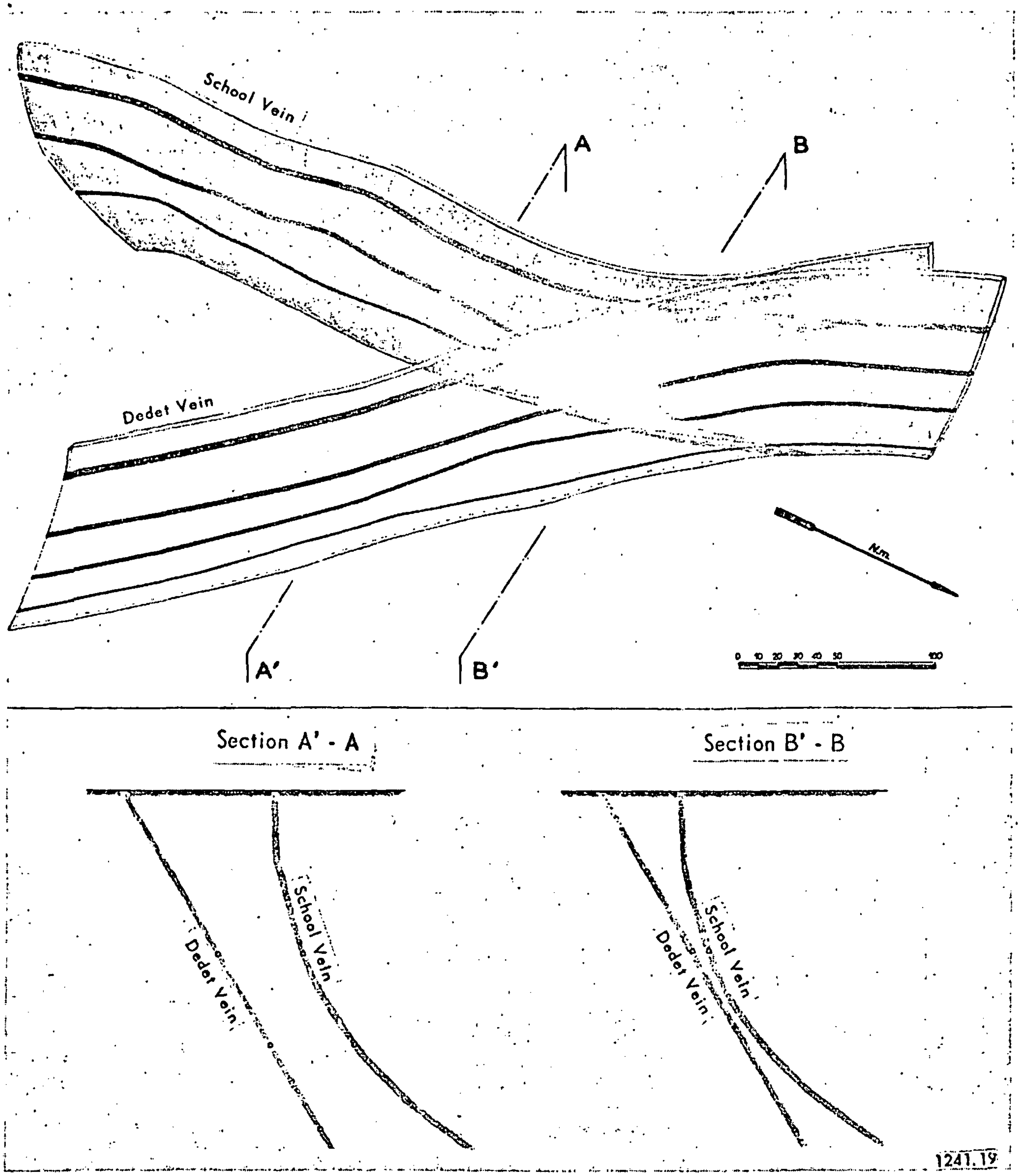


Figure 19. La Chapelle Largeau deposit

Dedet, parallels the contact, lies in a fault with a perfectly slickensided hanging wall and is filled with laminated red chalcedony containing lentils of pyritized gray chalcedony. The pitchblende occurs in the latter in minute inclusions about one-fiftieth of a millimeter in diameter, sometimes arranged in chainlets and surrounded by a succession of alteration halos.

From this vein springs another, known as the vein of l'Ecole. About this vein of gray quartz, which cements a breccia of red chalcedony and granulite, there is a system of numerous veinlets whose intersections produce large irregular enlargements. The two veins are undoubtedly contemporaneous, but the vein of l'Ecole was twisted upward by a slip parallel to the border of the massif which also affected the Dedet vein.

The deposit has been explored by mining operations to the depth of 170 meters and sporadic exploitation began in January 1958.

The deposit of the Commanderie (Fig. 20), located three kilometers from the previous one, is in the continuation of the fissure of l'Ecole. This fissure is filled with the same red chalcedony but the gray silica and pitchblende are absent. The mineralization has impregnated the enclosing granite, and especially the footwall, sometimes to a depth measurable in tens of meters. It occurs in a network of siliceous veinlets with pitchblende and pyrite or in impregnations of the mass of the rock by the "black products" and limonite, giving it a characteristic lead-gray color. In the upper levels, extensive alteration cockades are found consisting of gummite and concentric bands of "black products", limonite and kaolinite. Adventive faults spring from the main one and set limits to the mineralization, undoubtedly due to later leaching.

This deposit was discovered only two years ago. Mining operations have reached a depth of 100 meters; drilling, a depth of 200 meters. Important developments are expected from future operations.

Finally, on the southern boundary of the massif, systematic prospecting has disclosed a veritable mineralized belt which extends for some 50 kilometers from east to west. These mineralized localities mark out the contact a few tens of meters from the granulite along the border-faults conforming to the schistosity of the metamorphics. The latter are granulitized mica schists with beds of granulite intercalated in the highly micaceous rock and with aureoles of apatite. Uranium occurs on the surface in the form of abundant autunite in the joints of biotite-rich schists close to the granulite. At the water table level, autunite is succeeded by the "black products" associated with pyrite. But often all mineralization disappears.

Some outcrops have been excavated with success near the small town of Herbiers. They trend east-west and correspond exactly to the foregoing description except that they contain reniform red chalcedony. Mining operations reaching the depth of 80 m have shown the presence of the "black products" in the joints of red chalcedony fault breccia. But the bulk of the deposit consists of a network of siliceous veinlets with pitchblende and pyrite oriented N 10° W which are intersected in the east by the principal fault with formation of large swells. These veinlets are rooted in a granulite dike 20 meters north of the fault, and so there is no doubt that the mineralization originated within the granulite. This fact will serve as a guide in evaluating a number of other identical outcrops.

DISCUSSION

Comparison of these four groups of uranium deposits and outcrops leads to the following statements:

1. As has already been mentioned at the beginning of this article, and may well be repeated, there is an intimate relation between uranium concentrations and more or less granulitized rocks (Vendée, Limousin, Forez) or those with abundant aplite and pegmatite dikes (Grury) and a tendency toward enrichment in soda which may even lead to syenitization of certain parts of the granulite (Vendée, northern Limousin).

2. The mineralization is localized not only in large dislocation zones but also in locally reopened fissures within them, or more often, in small fractures associated with them, whether the zones of major dislocations are faults, mylonitized bands or lamprophyre or other dikes, provided only that they are richer in iron than the surrounding rocks.

3. The orientation of the veins is uniformly to the northwest with a few exceptions which are found in the Armorican or Variscan parts of the Hercynian folds.

4. There is a juxtaposition between fissures with pitchblende mineralization and the hematite zones in the enclosing rocks, the gangue itself being impregnated with hematite, except in the rare case of fissures which had been filled quietly, in the tension fissures which had not been rejuvenated, at the contact with lamprophyre dikes (Limousin) or of quartz (Forez). These deposits contain small but rich ore bodies in Limousin but they are never workable in Forez.

5. The sequence of mineralization and the simple paragenesis in the four mining divisions can be summarized as follows:

(1) pitchblende and the iron sulfides with constant association of pyrite and marcasite in chalcedonic silica;

(2) fluorite;

(3) followed at times by smoky quartz and the sulfides, sphalerite, pyrite, galena and chalcopyrite.

The smoky quartz is found as a gangue in the deposits lying not far from the great Tertiary dislocations (Forez) and does not occur to the southwest of the Massif Central.[8, 2]

Fluorite is very abundant at Vendée and Morvan, i.e., near the extremity of the branches of the "V" which represents the outline of this Hercynian structure of France.

6. In the deposits of Forez, northern Limousin and Vendée the exploitable blocks have horizontal dimensions rarely exceeding 100 meters; they are up to 25 m thick and are known to extend to the depth of 150 to 400 meters; in Morvan the workable bodies seldom exceed 240 meters in length, the simple veins springing from lamprophyres or ancient quartz veins seldom reach 10 meters in length.

Ten years of exploration have revealed several thousand uranium outcrops in the French Hercynian massifs, but only a few hundred have been shown to have direct relation to the twenty exploitable deposits.

Using such world-wide standards as may be derived from the still sketchy literature, these deposits may be classified on the basis of estimated tonnage of available uranium, as follows:

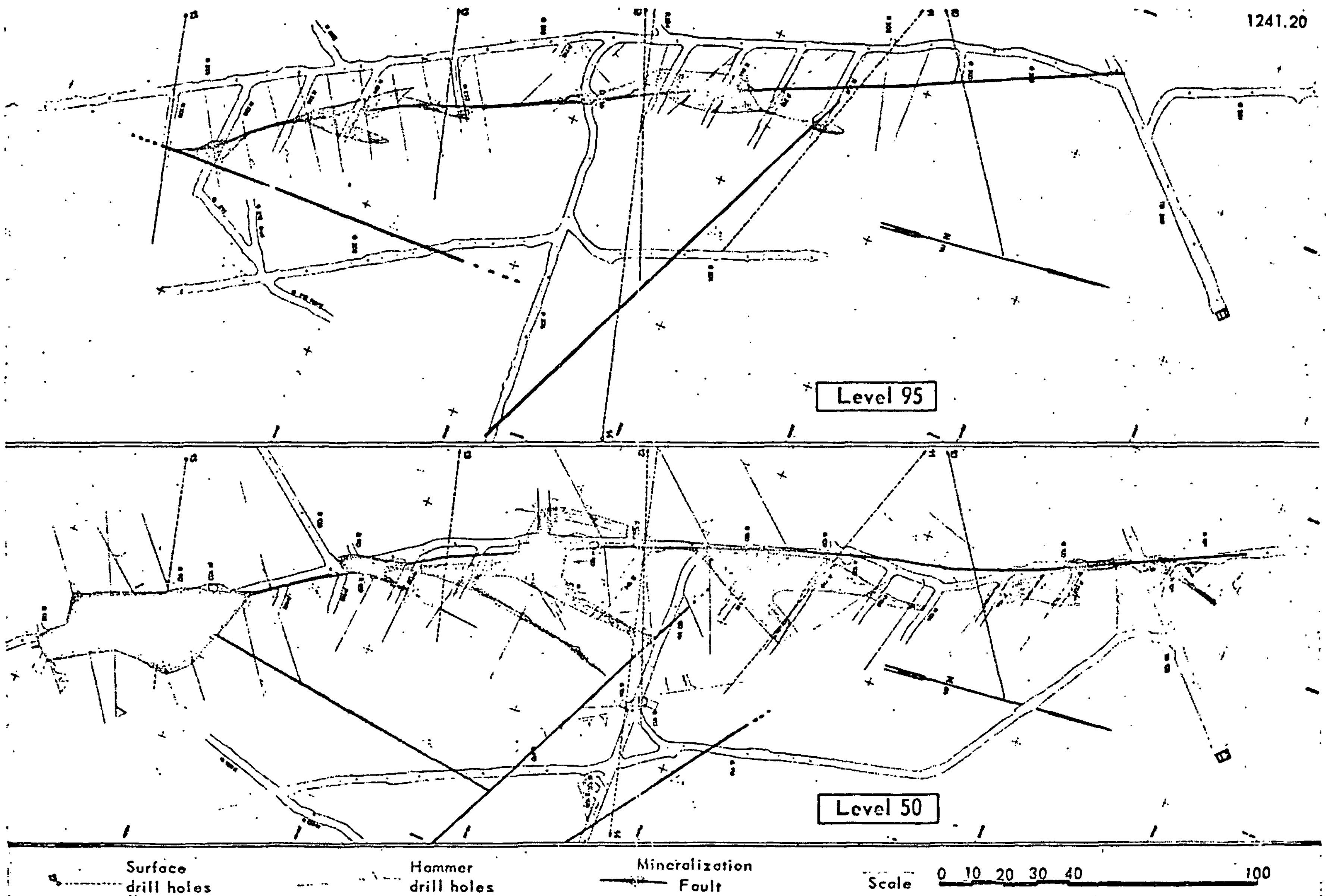


Figure 20. The Commanderie deposit

Deposits	*Forez*	*Morvan*	*La Crouzille*	*Vendée*
Small	4	4	3	3
Intermediate				2
Large	1		3	1

It is certain that this table has only a relative value since it is based on the actual tracing of ore bodies in different deposits and does not take into consideration possible future vertical or horizontal extensions.

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