UNDERGROUND NUCLEAR EXPLOSION EFFECTS IN GRANITE ROCK FRACTURING

S. DERLICH
COMMISSARIAT A L'ENERGIE ATOMIQUE (FRANCE)
Centre d'Etude de BRUYERES-LE-CHATEL

ABSTRACT

On the Saharian nuclear test site in Hoggar granite, mechanical properties of the altered zones were studied by in situ and laboratory measurements.

In situ methods of study are drillings, television, geophysical and permeability measurements.

Fracturing is one of the most important nuclear explosion effects.

Several altered zones were identified. There are : crushed zone, fractured zone and stressed zone. Collapse of crushed and fractured zone formed the chimney.

The extend of each zone can be expressed in terms of yield and of characteristic parameters.

Such results are of main interest for industrial uses of underground nuclear explosives in hard rock.

INTRODUCTION

The results of French underground nuclear tests are presented in this address. Their accuracy depends on utilised measuring methods and on chosen boundary definitions.

In order to show the value of results and to give data allowing the establishment of comparisons with underground nuclear tests in similar or different media, special interest will be given on these measuring methods and boundary definitions.

The test site was a granitic batholith in the Sahara desert near the Hoggar mountains. It has an elliptic shape 8 km along the main axis and 5. 6 km along the small one. The summit is 2 000 m. high, that is 1 000 m. above the level of Antecambrian table-land.

So, it was possible to get an overburden thickness of 1 000 m. under the highest point.

Geological and mechanical characteristics are given and will allow comparisons with other media.

This granite was studied by Lelubre (10), it is an alcaline granite with grains of regular sizes.

The mineralogical composition is shown below (in percent by weight).

Quartz	: 35
Microcline	: 37
Plagioclase	: 25
Biotite	: 2. 1
Muscovite	: 0. 6

The chemical analysis is (in percent by weight).

$Si O_2$	75, 8	$Na_2 O$	3. 8
$Al_2 O_3$	12. 5	$K_2 O$	4. 8
$Fe_2 O_3$	1. 3	$Ti O_2$	0. 1
$Ca O$	0. 6	$H_2 O$	0. 3

Grains range from 2 to 4 millimeters large. Some feldspar crystals reach 10 millimeters (photo 1). No traces of crushing are observed but quartz commonly present ondulatory extinction and microfolds may be observed in feldspar and biotite. Inclusions of hematite exist in feldspar and quartz. Veinlets of fluorite, calcite and quartz, several millimeters thick, are sometimes visible on the drift walls (2).

Microfracture study by autoradiography method (3) (photo 2) shows numerous permeable fractures of different kinds : along the cleavage of feldspars, as separations of two contiguous quartz crystals along their common boundary. It is impossible to identify preferred orientations in microfractures.

In the rock mass, several sets of fractures are sorted into tectonic faults, or in fractures due to growth and adjustement of the granitic batholith (2). These sets cut the rock mass into strata and cubic shaped blocks, whose dimensions vary from 50 cm to several meters. These fractures are almost filled with clay, calcite or fluorite. Most of them are waterproof but some have permeability, and slight water falls may be seen in drifts.

Mechanical properties of rock were studied by in-situ seismic measurements and laboratory tests. The results are reported in the following table:

density	2. 63
Young modulus E	710, 000 to 930, 000 bars
Poisson's ratio (calculated from	

laboratory determined seismic velocities)	0. 30 to 0. 38
Uniaxial tensile strength	40 to 50 bars
Uniaxial compressive strength	2 000 b

Seismic waves velocities

compressionnal wave :	in situ measurement	5 850 m/s
	laboratory measurement	5 500 m/s
shear wave :	in situ measurement	3 230 m/s
	laboratory measurement	2 400 m/s

Porosity : 0. 3 %
Permeability : zero
Rock temperature : 30°
MOHR circles envelope (figure 1)(5)

METHODS OF STUDY

Methods for studying induced shock effects are similar to exploratory means utilized in exploratory wells or mining research : coring of interesting zones, well logging, television scanning and permeability measurements.

Two main elements had to be considered : radioactivity and high temperature in cavities. Radioactivity is concentrated in a puddle at the bottom of the cavity. It can be found in gas coming from bore holes. A high residual temperature was expected due to very low water content of the granitic rock. Several hundred degrees centigrade may be found near the shot point.

Exploratory holes were drilled from reentry drifts located at the level of zero point.

Rotary method could not be used from drillings more than 150 meters long. Turbodrilling (Dyna drill) with coring was used and permitted to reach 300 meters from the rotating head with an accuracy of 2 or 3 meters.

Two data were expected from the core examination :properties of fractured rocks and extent of damaged zones.

A shock wave has different effects depending on its amplitude. Temperature effect acts in cavity and on the walls which are melted and vaporized. After the explosion, rubble and a puddle fill up the bottom of the cavity. Farther away, mechanical effects only are involved in rock mass. Near the cavity, granite is crushed, but far away from it, material is unbroken.

Thermal and mineralogical changes are reported in another paper ; so, only mechanical properties will be studied in this report.

The geological examination of cores will permit study of fractures and then, determination of phenomenology.

Differentiation between pre and post-shot fractures : preshot fractures are always filled with mineral matter sometimes very thin. Explosion produced fractures have either fresh-looking surfaces or crushed sides. Fracture dipping is very important because it gives possibility to identify sets of parallel fractures (tectonic preshot diaclases or fractures tangential to the shock wave) or planes going through zero point (radial fractures). Core fracture examination cannot give complete spatial orientation of fractures. During the extraction phase, the core does not remain in initial position but turns with the inner core-barel around the drill hole axis.
Planes of such orientation are tangent to a core which is defined by its summit angle (figure 2). It is sometimes possible to say if fractures can or cannot be "radial". With regard to drilling length (100 to 150 m. for rotary drillings, 300 m. for turbodrillings), no attempt to get oriented core was made.

Fracture nature gives the possibility to distinguish tensile fractures from shear fractures.

Bearing of minerals, Hoggar test site granite is composed of quartz, feldspar and biotite. Crystals have quite different characteristics and their bearing may give data on developped stresses.

Preshot fracture opening

At the boundary of the fractured zone, effective stress is less than tensile strength of rock, but the remaining shock wave can open preshot fractures or diaclases. Core scanning cannot show if preshot fracture opening is due to explosion or to drilling.

Zone extents

Examination of the whole of the samples gives a possibility of defining characteristic zones. They are almost spherical around the shot point or cylindrical around vertical line through the shot point.

Microfracturing has been studied on thin sections with polarizing microscope.

So, core examination cannot give complete data on fracturing.

Orientation or direction and dipping of fracture planes are unknown. The interior of the drillings has been studied with a television set. Axial lenses give a view along the bore-hole and a rotating mirror allows wall study. (photo 3).

Knowledge of fracture permeability around nuclear explosion is important for safe or engineering use.

FIG 1

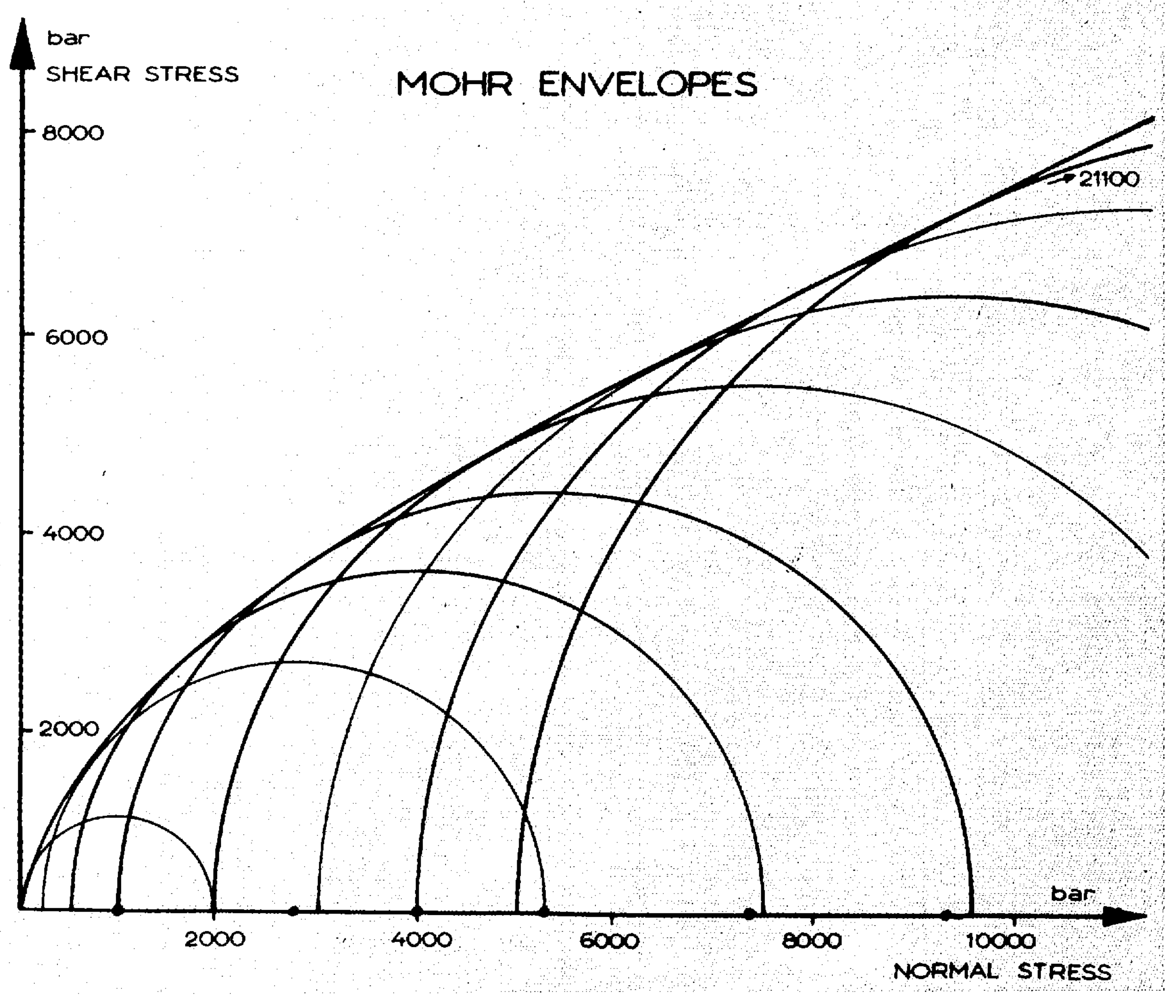
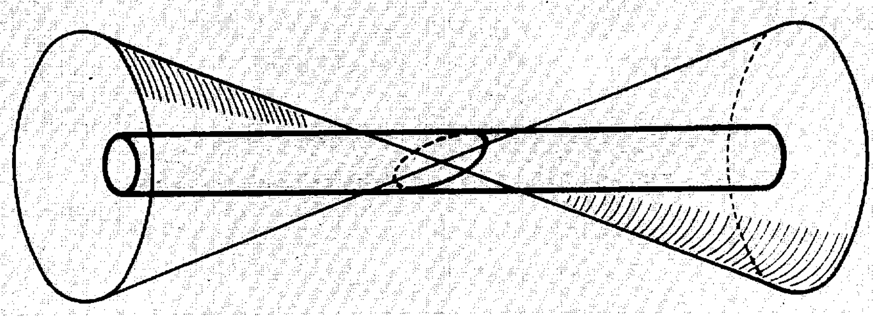


FIG. 2

THE CONE IS TANGENT TO THE FRACTURE



Measurements on short intervalls (5 to 10 m.) have been made in horizontal or angle holes. Water and air injection tests have been done. The main difficulties are to place inflatable packers in holes presenting sharp angles on the sides.

Study of seismic wave velocities in rock mass around the shot point, showed zones with velocities lower than preshot velocities.

A small yield chemical explosive has been fired into rock mass far from the shot point and a set of geophones were placed at the bottom of short vertical drillings on the other side of the shot point (8). Every gage gave the time of arrival which allowed calculation of velocity variations.

ALTERED ZONES

Synthesis of all results allows determination of zones with precise characteristics.

Figure 3 shows different zones whose average radii are :

$R_c = 7.3\ W^{1/3}$	R_c : cavity radius in meters
$R_b = 10\ W^{1/3}$	R_b : crushed zone radius in meters
$R_f = 26\ W^{1/3}$	R_f : fractured zone radius in meters
$R_r = 35\ W^{1/3}$	R_r : stressed zone radius in meters
	W : yield in kilotons.

Crushed zone

It is encountered from 7.3 to 10 $W^{1/3}$ (scaled distance in meters when W in kilotons).

Before chimney collapse, the crushed zone was spherical around the shot point. Core samples are chalky, coherent but friable. To the naked eye, it is possible to identify quartz and feldspars. Biotites look like black spots without glitter, sometimes laminated. Under microscope, alteration seems to be less important. Granite shows its preshot features, but it is highly damaged. Close spaced (1/100 of mm) intracrystalline microfractures break grains into regular or irregular sets. Birefringence has a notable reduction and shocked quartz are darker than preshot ones when examined in polarized light. Quartz crystals are broken in square shaped polygons (photo 4) or they present branching segments like river figures in metals. Planar surface sets and lamellas developp frequently in quartz. They indicate shear stresses acting on crystallographic planes (9) (photo 5). Glass veinlets have been injected in microcracks in quartz. Kink bands develop in many biotite grains and crystals are often crumpled by other crystals. Feldspars are bended and twins are often offset in a characteristic manner (photo 6).

Mechanical properties are given below :
compressionnal wave velocity (at atmospheric pressure) - 1060 to 1400 m/s average 1350 m/s.

Porosity (laboratory measurement) : 14.4 %.

Fractured zone

It extends from 10 to 26 $W^{1/3}$. Boundary between crushed and fractured zone is not precise. Its outer limit is identified to the first postshot fractures. So, opening of diaclases is possible farther on, but the boundary is not known.

Sets of angle fractures are often observed on cores. They are preshot fractures belonging to diaclase sets mapped in drifts.

Radial and tangential fractures seem to be rare. By location, angle discing fractures cut cores. They look like shear fractures produced from tridirectional laboratory tests. May be they are shear induced fractures. Great change in degree of fracturing is marked from one point to another point ; its depends mainly on preshot fractures.

From the crushed zone boundary granite is broken more and more coarsely. There are coarse sands, then gravels, then pieces of core from 5 cm to 15 cm long.

Stressed zone

Outside the fractured zone recovered cores present typical fractures. They break into parallel discs with irregular thickness, but always normal to core axis (photo 7). This phenomenon is called core discing. It is observed in salt mines (10) and in deep mines in quarzites (11), and depends on stresses in rock around holes. It is induced by drillings, and sidewalls of boreholes present some alterations (photo 8) in almond shape.

Orientation of this "almond" figure depends on the maximum principal stress acting on the borehole.

In boreholes of the Hoggar test site, this orientation is not constant, so it may be thought that stresses have not one precise direction, but are depending on preshot fractures. This hypothesis may be confirmed by typical fracture observed on a core sample where discs were interrupted by an angle fracture showing that stresses change from one side to the other side of the fracture (figure 4).

Discs extend to a distance of 35 $W^{1/3}$, for borehole diameters from 80 to 90 cm.

Chimney

It is formed upon collapse of the cavity when the pressure of explosion produced gas is low enough. This pressure decreases quickly and the crushed zone is not able to support itself (figure 5).

Every cavity of the Hoggar test site collapsed and formed a chimney (12).

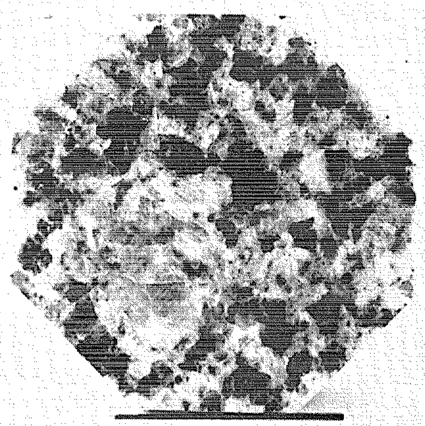


PHOTO 1

14 mm

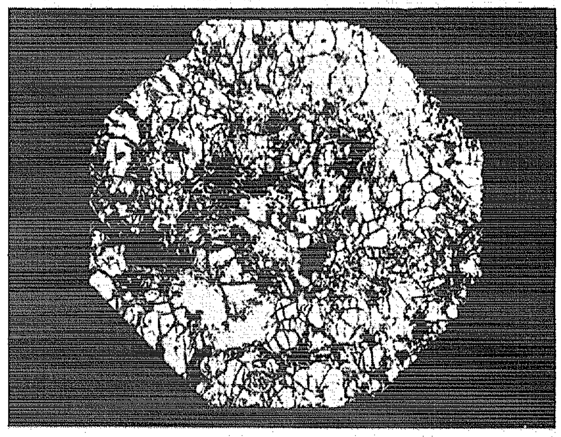


PHOTO 2

14 mm

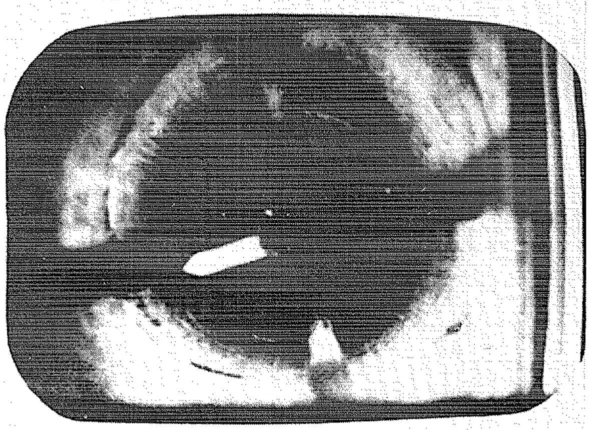


PHOTO 3

12 cm

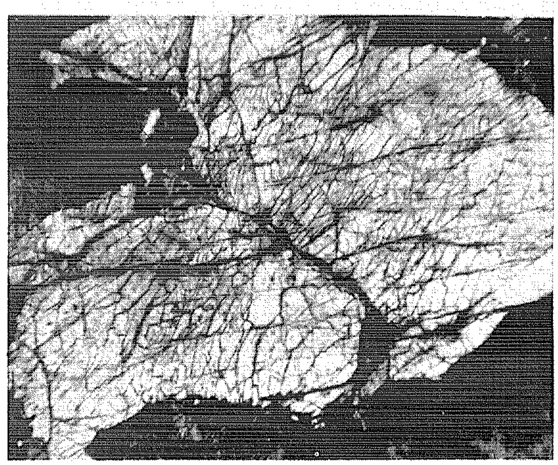


PHOTO 4

1mm

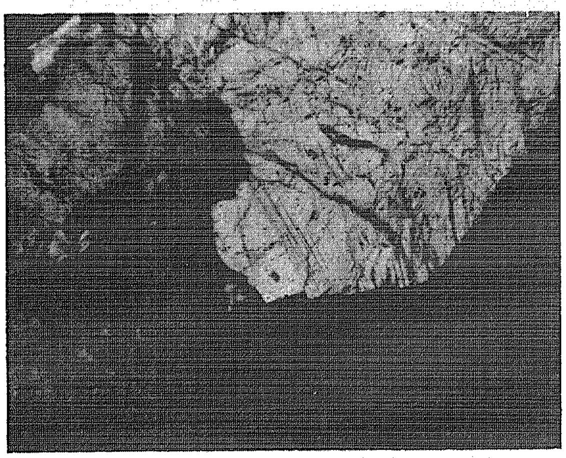


PHOTO 5

0.5 mm

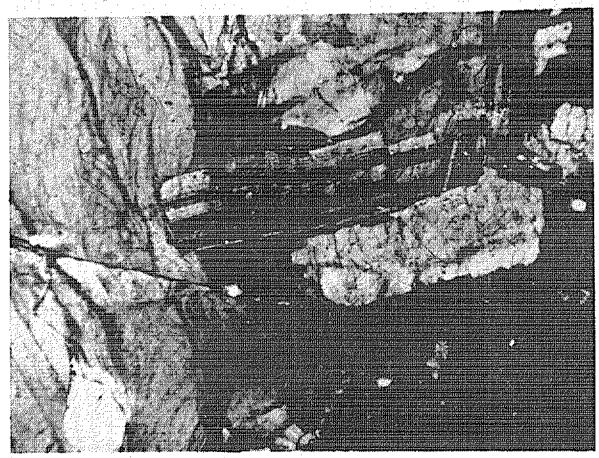


PHOTO 6

1mm

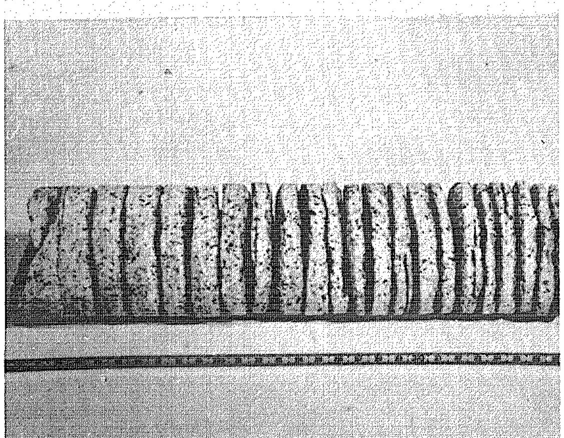


PHOTO 7

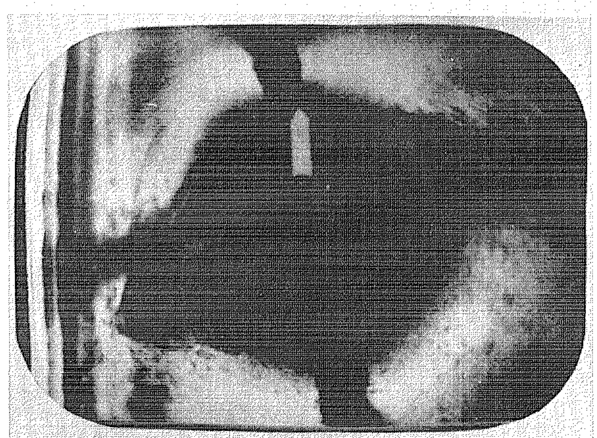


PHOTO 8

12 cm

FIGURE 3 VERTICAL CROSS SECTION THROUGH A CHIMNEY

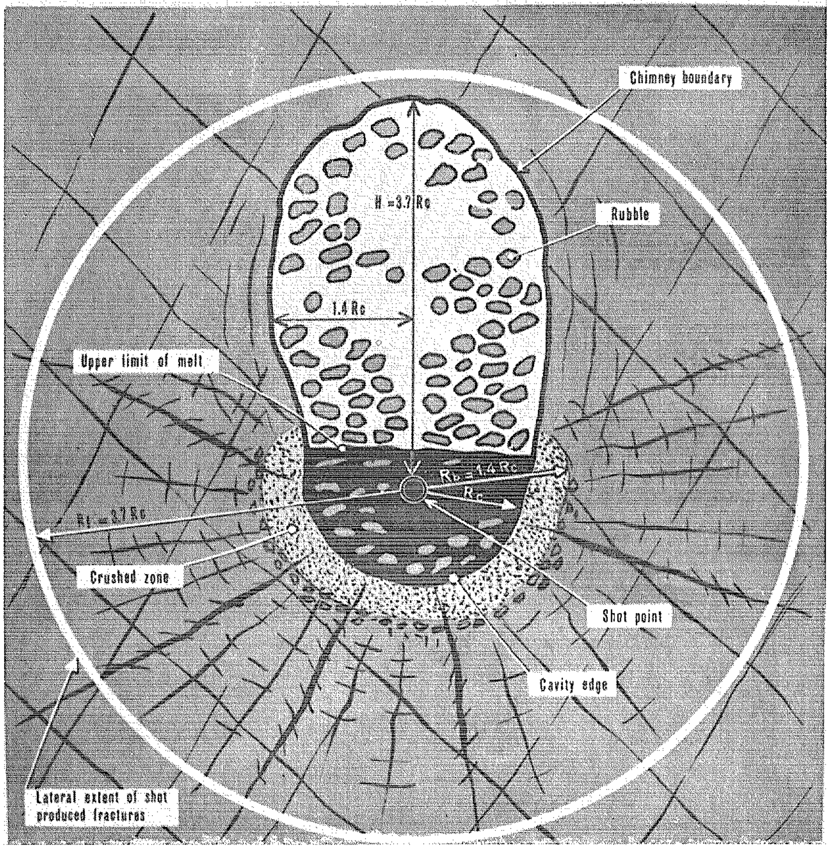


FIG. 4

ANGLE FRACTURE INTERRUPTING SEVERAL DISKS

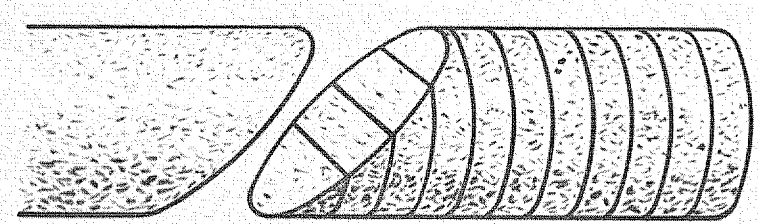


FIGURE 5

Cavity vault before the chimney formation

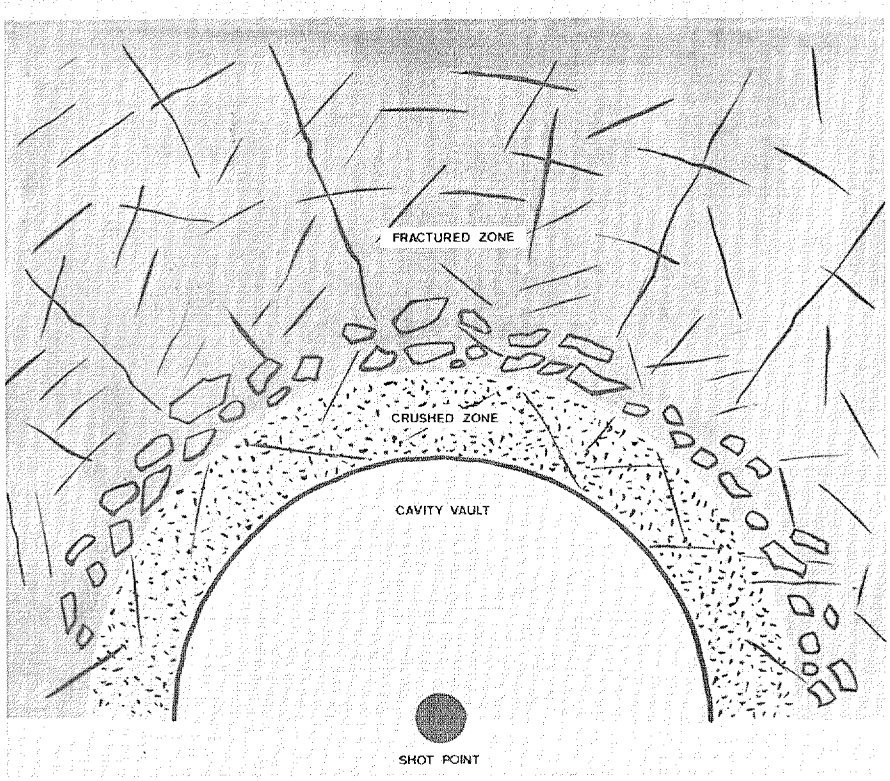


FIGURE 6

Exploratory drillings

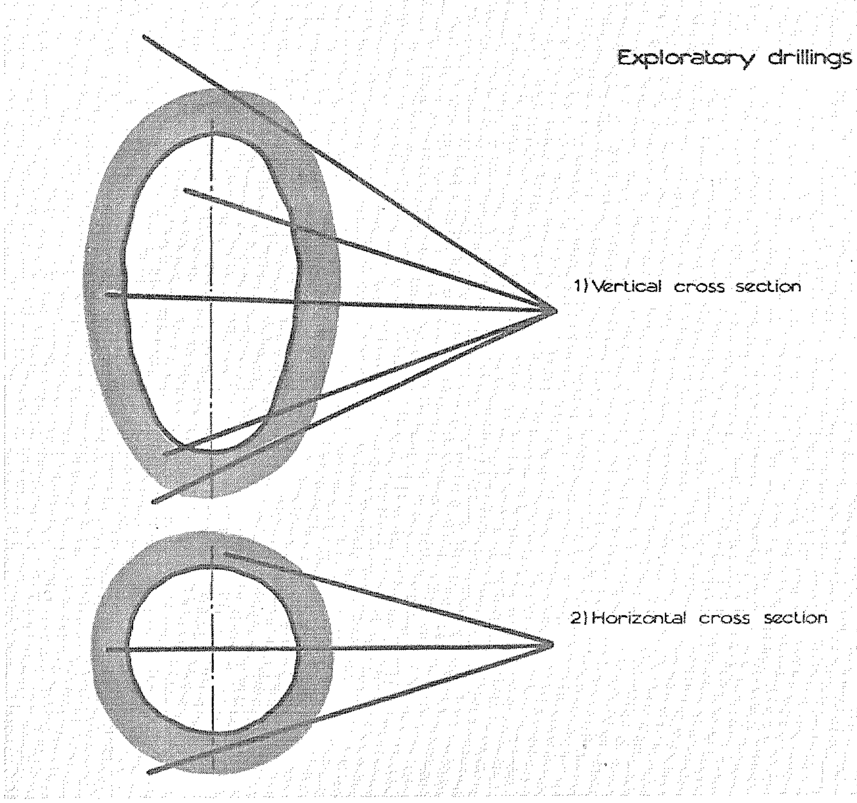


FIGURE 7

Permeability data

ZONE		CRUSHED	FRACTURED	STRESSED	UNFRACTURED	ABOVE THE CHIMNEY
Distance to shot point (meter)		10	26	35		
Permeability (milli darcy)	horizontal drill holes	2	45 to 90	30 to 40	20	
	Inclined drill holes		590	50	40	140

FIGURE 8

Seismic velocities

ZONE		CRUSHED	FRACTURED	STRESSED	UNFRACTURED	ORIGINAL VELOCITY
Distance to shot point		10	21 26	30 35	71	
Compressional wave velocity	laboratory measurement	1350	3500	4000 4240		
	in-situ measurement			5300	5600	5850

Chimneys were explored at different levels by means of angle holes (figure 6) which crossed rubble from side to side or which failed by collapse of the side-walls.

Rubble range between 4 and 10 cm.

Size of chimney is 3.6 cavity radius height above the shot point and 1.4 cavity radius width at level 2 cavity radius above the shot point.

Chimney existence introduces variations in rock mass :
opening of extension fractures in the surrounding rock, stress increases in the lateral walls. Permeability is also influenced by the chimney.

After displaying main geological data, mechanical and engineering results may be given.

Permeability.

For crushed zone samples (5) air permeability ranges from 6.5 to 9.5 md in-situ measurements (7) are given in this table (figure 7).

Seismic waves velocities (figure 8). (13)

They were measured both in-situ (8) and in the laboratory on samples.

Final results depend on media properties but also on experimental methods such as display of gages in boreholes or at the surface. Care must be taken when using them for predictions and correlations. (14)

CONCLUSION

Studies effected in boreholes drilled in altered zones around an underground nuclear explosion allowed us to get good knowledge on fracturing effects in Hoggar test site granite.

Seismic experiment results gave data on velocity variations and on porosities.

Mapping of altered zones is possible and main physical and geological data are known.

Extension of these zones is represented by an experimental law depending on the yield of the device and on characteristics of the medium.

BIBLIOGRAPHY

(1) - LELUBRE M. Recherches sur la géologie de l'Ahaggar. Bul. Ser. carte Géo. Algérie 2ème série n° 22 Alger 1952.

(2) - SANSELME H. Rapport C.E.A. (Unpublished). Le Taourirt Tan Afella et sa région. C.R.A.S. Vol. 256 - page 3160 (1963).

(3) - LEVEQUE M. et VIGNEAUX - L'autoradiographie dans l'étude de l'altération des roches. International Atomic Energy Agency - VIENNE 1967.

(4) - DUCLAUX F. (unpublished) (1962)

(5) - HABIB P. - Etude de deux granites - contrat Ecole Polytechnique.

(6) - DERLICH S., DUCLAUX F., SARCIA J.A - Etude de la cavité (1962) (unpublished).

(7) - FAURE J. - Rapport C.E.A. - Explosions nucléaires souterraines, effets sur la roche d'un massif de granite, transformations d'ordre mécanique - décembre 1968 (unpublished).

(8) - DUCLAUX F. Rapport C.E.A. - Etude seismique des zones fracturées (unpublished).

(9) - DERLICH S. - Métamorphisme de choc dans les cristaux de quartz d'un granite soumis à une explosion nucléaire souterraine. C.R.A.S. t. 267 - pages 681-683 (1968) série D.

(10) - GIMM W.A.R., PFORR H. - Breaking behaviour of salt rock under rockburts and gas outburts. Fourth Int. Conf. on Strata Control and Rock Mechanics - New-York City. May 4-8, 1964.

(11) - LEEMAN E.R. - Nat. Mech. Eng. Res. Inst. Rock Mech. Special report : n° 29 Measurements of stress and ground movement in 35 E 12 E Stope Cinderella Section E.P.R.M. - Pretoria, March 1959.
- n° 32 Stress measurements in 64 E Stope, Driefenstein Section.
- E.A.P.M. - Pretoria C.S.I.R. Report CN301 november 1959.

(12) - DUCLAUX F. and all - Liaison entre le rayon et la durée d'existence des cavités créées par les tirs nucléaires souterrains. C.R.A.S. tome 264 pages 496-497 (1967) série B.

(13) - FERRIEUX H - Ondes seismiques de compression liées aux explosions nucléaires souterraines (1967) (unpublished).

(14) - ALBARET A., DUCLAUX F. - Contenu spectral des mouvements seismiques dus aux explosions nucléaires souterraines - C.E.A.-R-3 767.