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IGNEOUS ROCKS OF ALPINE AGE ASSOCIATED WITH KEUPER MATERIALS IN THE IBERIAN MOUNTAINS, NEAR TERUEL (SPAIN)

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RESUMEN

Se describen algunos caracteres geológicos, petrográficos y geoquímicos de unas rocas ígneas, que en pequeños afloramientos aparecen asociadas a materiales del Keuper.

Estas rocas, que estaban citadas como ofitas, corresponden principalmente a facies granudas entre sienitas y monzogabros.

El ambiente de los afloramientos, relaciones de contacto, caracteres petrográficos y químicos, parecen indicar que las rocas ígneas fueron el resultado de procesos de metasomatismo originados por fluídos sílico-alcalinos que transformaron los materiales encajantes margo-evaporíticos del Keuper.

PALABRAS CLAVE: **Procesos de transformación. Rocas ígneas alpinas: sienitas-monzogabros.**

ABSTRACT

In the present work, some rocks of igneous facies associated to Keuper materials, are studied.

These rocks, previously referred to as ophites, consist in fact of plutonic rocks, compositionally ranging from syenites to monzogabbros.

Field, petrographic and geochemical data appear to indicate that these igneous rocks facies were a consequence of metasomatic transformation processes that took place between allocthonous silica-alkaline elements and suitable wall-rocks, constituted, in this case, of evaporitic marls of Keuper facies.

KEY WORDS: **Transformation processes. Alpine igneous rocks: syenites-monzogabbros.**

Introduction

S-SE of the city of Teruel and within the Iberian Mountains, there are some small outcrops of igneous rocks (0'5-4 km^2), all of which have been referred to as ophites: Bakx (1935), Martin (1936), Orti (1974), IGME (1978-80), Orti y Vaquer (1980). San Miguel (1936) was the first to establish some difference between these rocks and the ophites. So in this area this author mentions the existence of rocks such as diabases and teschenites. On the ophites, in general, there exists a great deal of bibliographic data, mostly due to a doctoral thesis done in the Dept. of Petrology of the University of Zaragoza (Lago San José, 1979) and to other authors: Bakx (1935), Martin (1935), Lamare (1935), S. Miguel (1936), Thiebaut (1973), Meurisse (1974), Durand-Wackenheim (1974), Walgenwitz (1976), Castellarin, *et al.* (1978), Lago (1979), Lago y Pocovi (1980), etc.

Although the geological characteristics are very similar to the ophitic ones, field and petrographic studies point towards different types of plutonic rocks, mainly of syenitic to monzonitic composition. In some particular points, and within the same outcrop, there are also granitic and hornfelsic rocks, which may contain sillimanite and other interesting minerals (e. g. as in the Camarena area, see Sánchez Cela, 1981, 1982).

The singular and constant association between the "ophitic" and related rocks with the Triassic materials of Keuper facies has caught our attention, which has lead us to think of the possibility that there exists some relationship between the evaporitic marls and the origin and evolution of those rocks.

Geological setting

Structural framework

Al these rocks were found to follow structures of Alpine age, which are broadly parallel to the Hercynian ones.

The main outcrops of igneous rocks in the region

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are related to this structures (NW-SE, fig. 1). Other neigbouring igneous rocks, from andesites of Permian age (Albarracín mountains) to basalts of Jurassic age (Javalambre zone), also follow these trends.

Owing to their particular properties, the Keuper materials generally exhibit a manifest deformation in the contact with the igneous rocks, as well as in the nearby areas; that is the case with many ophites in the Pyrenees, which appear within the upper part of Keuper and even, in upper stratigraphic levels, as intrusive-allocthonous masses. These intrusive phenomena would, in our opinion, be the reason why the contact- relations and hence the mechanisms of emplacement of these and other similar igneous rocks, have often been the subjects of different interpretations.

Luckily, in the Teruel area the igneous rocks facies exhibit a gradational transition to the Keuper-wall materials.

Broadly, in the Teruel area, two modes of ocurrence are present: substratiform and sub-intrusive (fig. 2a-b). In both modes there is a gradational transition between the igneous rocks and the wall-rock materials, through an intermediate zone (from 20 to 100 cm width), that we will subsequently refer to as mixed-microlithic zone.

Also in this area there are centimetrical bodies, which seem to be isolated from the main mass that have been interpreted by some authors as fragments originating from the principal mass, broken off by tectonic processes. Our field and petrographic studies show that these small bodies or fragments are the result of independent, simultaneous and punctual petrological processes spatially unrelated with the principal mass.

These conclusions have been obtained after a petrographic study. Many of the assumed "fragments" correspond to what we have defined as mixed and microlitic facies that grade into Triassic wall materials, where grained facies have not been developed

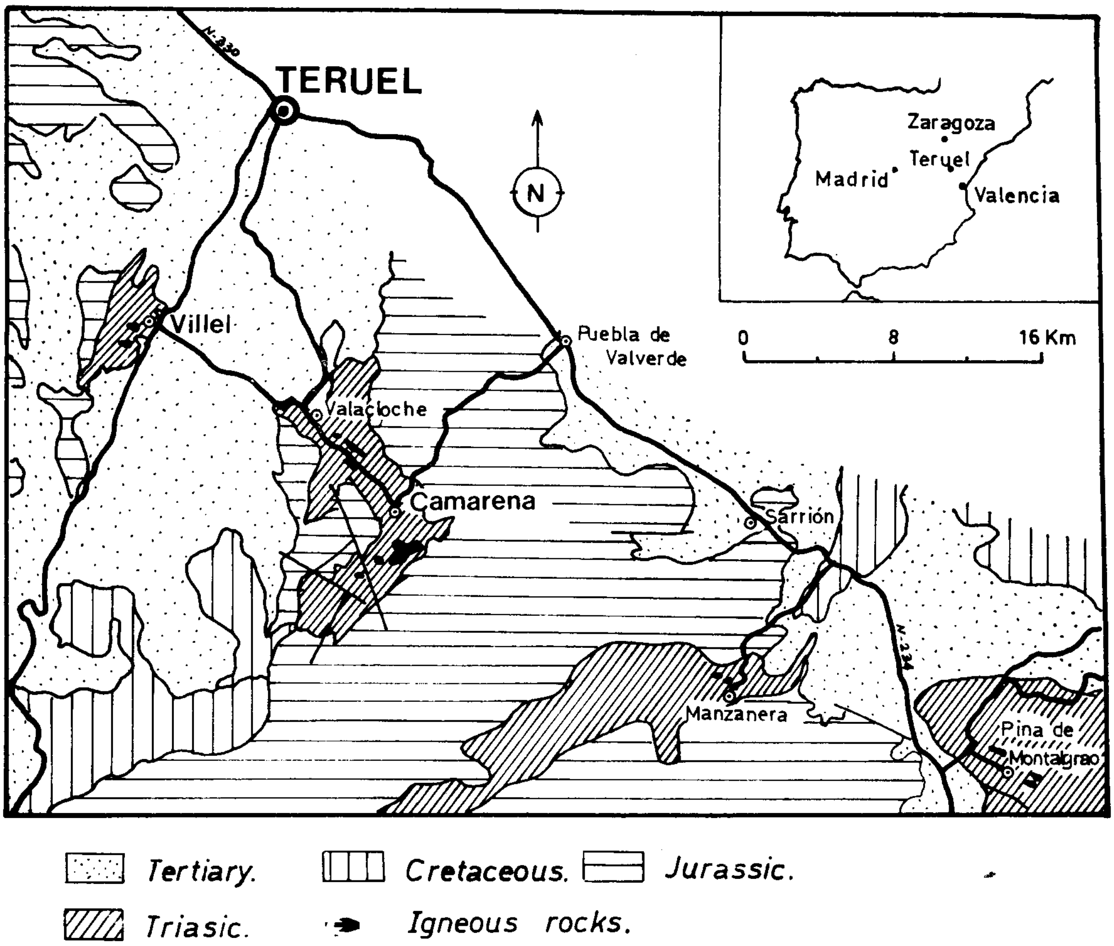

Fig. 1.—Schematic map with the location of igneous rocks outcrops near Teruel.

possibly because of their low physical-chemical gradients.

These features, together with the lack of any presumable tectonic-petrographic features in these supposed fragments, seem to invalidate the idea of their origin as worn-off fragments of the main mass.

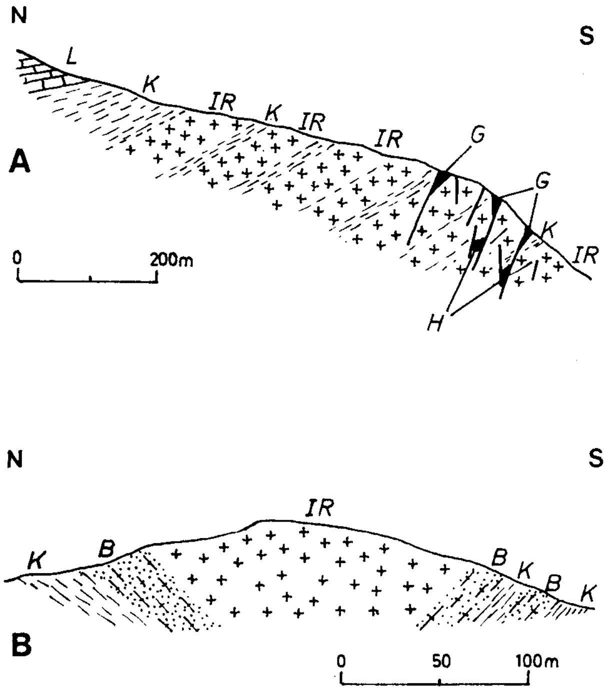

Fig. 2.—Schematic cross-section, A: sub-stratiform type (Camarena); L=Liassic; K=Keuper; IR=Igneous rocks; G= =Granitic rocks; H=Hornfel rocks. B: sub-intrusive type (Villel); K=Keuper; B=border-microlitic facies; IR=Igneous rocks.

Keuper-wall materials

As we have already stated, the igneous rocks in the Teruel area are always associated with Keuper materials. These materials have been studied by several authors (Bakx, 1935; Martin, 1936; Orti, 1973; IGME, 1978). Although some of them have distinguished up to five sublevels, these are very difficult to identificate because of their mutability.

Near the igneous outcrops, however, two broad units can be distinguished: Upper and Lower Keuper. The latter, in general, is constituted by an alternation of argillaceous lutites and gypsum with intercalations of carbonatic rocks and some evaporites. The former is characterized by the red-colour in some levels, although their composition are similar, consisting of calcareous sands that alternate with lutites that contain gypsum and other salts.

The Camarena-Valacloche outcrops appear to be associated with the Lower Keuper levels. In other localities, e. g. Villel, the igneous rocks are associated with the Upper Keuper levels.

The Keuper evaporitic marls exhibit in many places interesting minerals named "Jacintos de Compostela" and "Teruelites". The "Jacintos" are euhedral-bipiramidal quartz that generally enclose abundant inclusions of argillaceous and salt minerals. The "Teruelites" are minerals that correspond to dolomite structure with Fe and variable rate of Mg.

An interesting observation, not yet confirmed on a regional scale, is that those rare minerals appear more frequently when endogenetic or mechanical processes take place. So, in the Teruel area, both Teruelites and Jacintos are more abundant in those places where igneous facies rocks exist or where tectonic disturbances are more evident.

The Liassic-Jurassic levels are constituted by various carbonatic rocks: calcareous dolomites, magnesian-limestones and limestones.

Paleozoic materials do not outcrop in this area. They outcrop to the NW and SW, where they are constituted of shales and phyllites, that alternate with sandstones and quartzites.

We would like to point out here the importance of the authigenetic processes in the Keuper materials, a consequence of the suitable mineralogical and chemical features of these levels.

These processes (Marfil, 1970; García Palacios *et al.*, 1976; García Palacios et Lucas, 1977), make us think that these materials powerfully constitute a "suitable geological habitat" for petrological transformation processes when the physical-chemical environment is modified.

It is well known among petrologists that the sediments constituted by argillaceous minerals (mainly illites and chlorites) together with various evaporitic materials ($CO_3^{=}$, $SO_4^{=}$, Cl^-, etc ...) are very suitable for mineralogical transformations from the very first diagenetic stages. So in the last diagenetic or anchimetamorphic stages K-feldspar, Na-plagioclase and some other micaceous minerals as well as Quartz can be formed.

Obviously those petrological changes will be more important if the physical factors overpass the diagenetic ones in a chemically open system, for exemple when the suitable Keuper materials are affected by the contribution of magmatic or metasomatic fluids.

Petrology

Our field studies indicate that the igneous rocks-facies are always located in the Keuper levels. The Paleozoic materials in nearby zones do not include equal or similar rocks. We have observed that in all of the outcrops (sub-stratiform and sub-intrusive) there exists a gradational transition at millimetrical scale between wall-Keuper materials and the igneous facies rocks.

From the wall-Keuper to the dominant igneous facies rocks of the centre of an outcrop, there is a gradational transition through different rocks defined by us as "border facies": mixed rocks, microlithic facies and protodiabasic facies. The dominant rocks that form the main bulk of the outcrops are constituted by grained-rocks, mainly syenites-monzonites. Other rocks may also exist, such as monzogabbros and basic alkaline rocks.

The contact-relations in the Camarena outcrop, where there exists a greater petrographic variation, show that the monzogabbros and the basic-alkaline rocks were the first to be formed during the petrological processes. Subsequently the syenite-monzonite rocks were formed. In some particular points in relation with fracture brecciation zones, there are interesting quartz feldspathic (granitic) and hornfels rocks, which contain sillimanite and other minerals. These rocks are of a later origin in relation to the others (Sánchez Cela, 1981-1982).

The field, petrological and structural features seem to point towards a certain relationship between the sedimentary wall-rocks and the lateral evolution of the igneous rocks, deduced, among others, from the following features:

- Gradational transition from sedimentary to igneous rocks through "mixed" or "hybridous" facies of intermediate petrographic-chemical composition.
- Irregular distribution shown by the alternation of different igneous rocks and the wall-Keuper materials to all scales with gradational transition among them.
- Existence, in some cases, of small masses isolated from the igneous-bulk of mixed and hybridous facies within the sedimentary rocks, that are interpreted as independent and simultaneous punctual processes, as stated above, and
- Existence of small and very shallow outcrops of igneous rocks, without roots, constituted only by mixed or hybridous facies rocks with abundant Keuper remains, more or less transformed, with a gradational transition between both petrographic facies.

Petrographic types

Prior to a petrographic description of the different facies of the rocks it should be noted that the petrographic types established here, according to the leucocratic minerals, could be, in some cases, in contradiction to their chemical composition. So a "typical syenite" can geochemically corespond to a subsaturated rock.

This lack of correspondence between the petrographic and the chemical composition, constitutes an interesting petrological feature, that we shall comment on below.

From the wall-Keuper materials to the center of the outcrops, regardless of the existence of the frequent repetitions, the following petrographic facies, can be established.

a) Mixed or hybridous rocks.

b) Microlithic-diabasic rocks.

c) Grained rocks.

The "mixed or hybridous rocks", located in contact with the Keuper materials, within the "border facies" constitute, in our opinion, a valuable "tool" to understand the meaning of the petrological processes that took place in the origin of the igneous rock-facies.

These hybridous rocks, are constituted by chloritic-illitic minerals, more or less recrystalized, which include Fe-titaniferous minerals, quartz, feldspars, apatite and other accesory minerals. In spite of their micrometric size the petrographic features indicate that such minerals, of a subsequent origin, have been developed within sedimentary materials more or less transformed.

The "microlithic-diabasic" facies correspond to the intermediate rock-types between the mixed and the grained rocks. Here their mineral composition is more easily recognized. It is associated with the abundant crystals of chlorites, Fe-Ti, and argillaceous minerals. K-feldspar, plagioclase, biotite, quartz, apatite, zircon, rutile and sometimes carbonates can also exist as subordinate-accesory minerals.

One of the most interesting features in these rock-facies is the presence of the reactions-series between the chlorite minerals and the quartz; this presence will be commented on in detail together with the "grained" facies.

The "grained" rocks are the most abundant facies in the outcrops. In general the petrographic types correspond to syenites, monzonites, monzogabbros and basic alkaline rocks.

In some points and in fracture zones there are granitic and hornfel rocks of subsequent origin (Sánchez Cela, 1981-1982).

QUARTZ-SYENITES:

These petrographic types are only present in Villel outcrop, where they constitute the central part surrounded by syenite-monzonite as well as diabasic-microlitic border facies. These coarse-medium-grained rocks, and light colours are formed by K-feldspars, plagioclase, quartz chlorite minerals, ilmenite, as main componentes, and biotite, apatite, circon and perovskite, as subordinate-accesory minerals (figure 3). The quartz, always appear as a subsequent mineral, in interesting reactions-textures with other

Fig. 3.—Quartz-syenite from Villel sub-intrusive outcrop. Association K-feldspar-plagioclase that enclose abundant chloritic-argillaceous inclusions. × 60. NC.

minerals, mainly with the chloritic ones (fig. 4). The K-feldspars and the plagioclases usually appear associated among them, the latter constituting the nucleus of the crystals. Both exhibit many inclusions of argil-micaceous minerals (principally chlorites) (fig. 5). The chlorites, in these rocks, appear as isolated crystals associated with biotites. In many

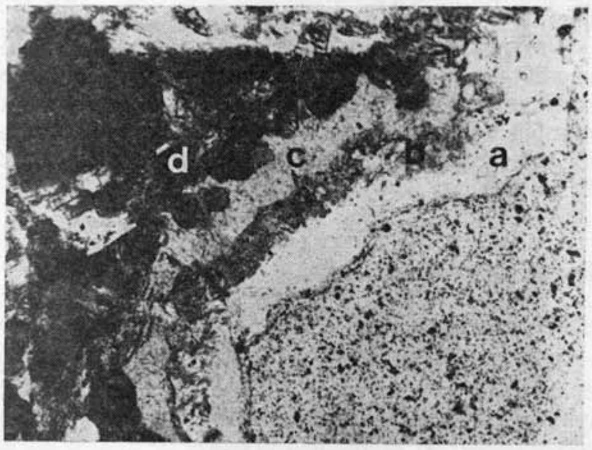

Fig. 4.—Reaction-transformation textures between chloritic-serpentinic minerals and quartz in a syenitic rock from Villel. a=quartz; b=chlorite rich in silica (α type); b=chlorite-ripidolite (β type); d=chlorite-serpentinic (γ type) (Analysis in Table 2). × 120. NC.

cases, in the points of contact with the quartz, they exhibit coronitic-reaction textures that shall be outlined below.

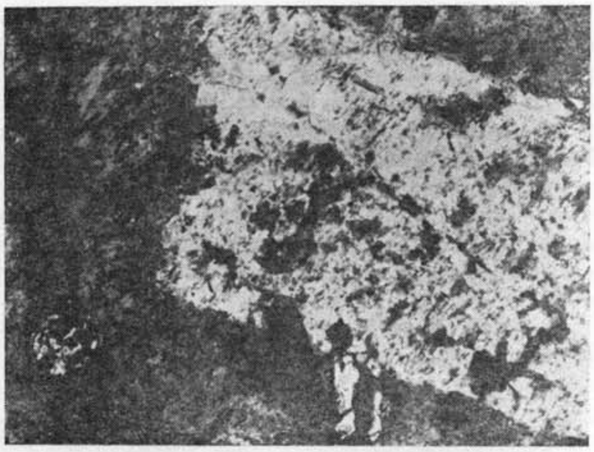

Fig. 5.—Association K-feldspar and plagioclase that enclose chlorite-argillaceous minerals and some apatite in a syenitic rock from Villel. × 120. NC.

SYENITE-MONZONITES:

These rocks are the dominant types in all the outcrops. They are constituted by a variable ratio of K-feldspar and Na-plagioclases, as well as chloritic minerals as their main components, and ferriferous and titaniferous minerals, biotite, quartz, apatite

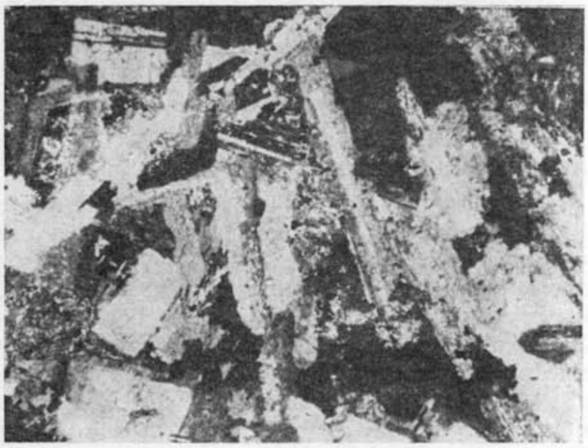

Fig. 6.—Monzonitic rock from Camarena outcrop. × 60. NC.

and zircon as subordinate-accesory minerals (fig. 6). The most basic terms (monzonites) exhibit clinopiroxenes from moderately to well cristallized and generally associated to the chloritic minerals. The quartz accesory mineral in the syenites, is of subsequent formation. It is always located in some interstices transforming other minerals, mainly chloritic minerals. The K-feldspars and plagioclases, as in the quartz-syenites, include many argil-chloritic minerals.

MONZOGABBROS:

These rocks, only present in Camarena outcrop together with the basic alkaline rocks, are the oldest within the "igneous" Keuper series. They are constituted by a variable ratio of felspars (K-feldspars and Na-plagioclases) as well as clinopyroxenes (principally-magnesian augites) and chloritic minerals, as their main components; and asbestiform ferromagnesians, amphibole, biotite, ilmenite, apatite, zircon, rutile, perovskite and carbonates, as subordinate-accesory minerals (fig. 7). In some samples there are interstitial crystals of quartz reacting with and transforming the other minerals.

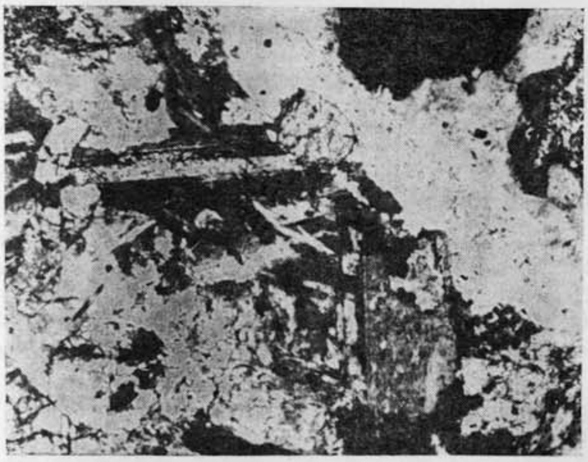

Fig. 7.—Monzogabbro from Camarena outcrop. × 60. NC.

BASIC ALKALINE ROCKS:

These types of rocks are less frequent. They are always associated to the monzogabbros. They are constituted by "nepheline", K-feldspar and asbestiform ferromagnesians, as principal minerals; chlorite, plagioclase, clinopyroxene, amphibole, biotite, ilmenite, apatite, sphene, zircon, rutile, perovskite, prehnite and carbonates, as subordinate-accesory minerals. There also exists a mineral with analogous petrographic features as the feldspars, which is very difficult to identify due to the presence of many argil-chloritic inclusion-minerals, that we identified as "nepheline" due to their morphological-optical features and to the chemical composition of these rocks (table III, analysis 3).

GRANITIC AND HORNFEL ROCKS:

Both related rocks are of subsequent origin in relation to the others. These rocks are only located in one outcrop (Camarena zone) and associated to punctual-fracture zones (Sánchez Cela, 1981 and 1982).

As we have already stated in the above works, differential transformation processes, between the "granitic elements" and the wall-rocks are developped. When the wall-rock corresponds to the igneous rocks, e. g. syenites-monzogabbros, these rocks appear to be affected by silicification processes, as well as a mineralogical recristallization-restructuration.

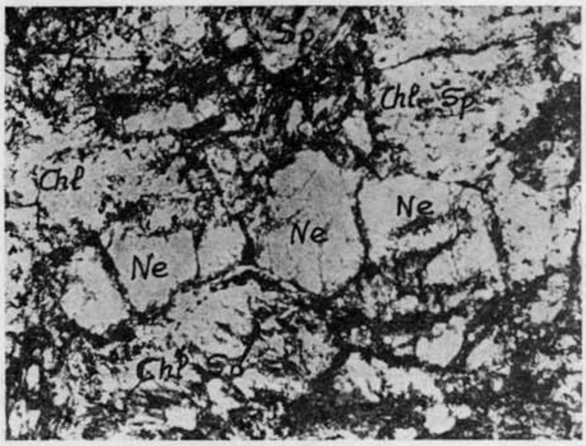

Fig. 8.—Basic-alkaline rock from Camarena outcrop. Ne= =nepheline with chlorite-argillaceous inclusions; Chl-Sp= =chlorite-serpentinic minerals. × 120. NP.

On the other hand, when the granitic elements affect former rocks with remains of Keuper materials, in some points, hornfel rocks with high gradients paragenetic minerals can be formed (hornfel with spinel, sillimanite, orthopyroxene, cordierite and other minerals).

The existence of rocks with very different physical-conditions associated to centimetrical-metrical scale, such as non metamorphized Keuper materials and hornfels with those paragenesis, that involve interesting petrogenetic problems, was exposed and explained in an previous work (Sánchez Cela, 1982).

Some mineralogic data

CHLORITIC MINERALS:

This wide and many times badly defined group of minerals is always present in all the petrographic types. These minerals can appear in several forms and textures: 1) as isolated crystals; 2) associated to magnesian biotites; 3) as chlorite-serpentinic minerals, and 4) in reaction-transformation series associated to other minerals of subsequent formation, mainly quartz. The first type, according to microprobe analysis, corresponds to "near ripidolite" types (table 1b and 2a). The chlorite-serpentinic minerals, mainly present in monzonites, monzogabbros and in basic-alkaline types, according to the analysis (table 1c and 2b) appear to correspond to an intermediate mineral between "chlorite" and "serpetine".

The contacts between the chlorites and the quartz usually exhibit interesting reaction - transformation textures.

TABLE 1

Microprobe analyses (Camarena outcrop)

	a	b	c	d	e	f	g
SiO_2	35'97	30'93	35'10	39'60	49'20	46'80	50'40
Al_2O_3	14'51	19'60	13'90	8'40	4'90	2'60	8'30
FeO(*)	23'35	21'94	15'20	11'20	6'40	10'90	10'00
MnO	0'20	0'30	0'20	0'10	0'20	0'20	0'20
MgO	11'20	14'97	22'80	36'20	14'80	13'60	18'20
CaO	-	-	-	-	21'40	22'40	9'50
Na_2O	-	-	-	-	0'30	1'60	1'20
K_2O	7'70	0'73	0'20	0'10	0'10	0'10	-
TiO_2	3'20	0'60	0'40	0'20	2'10	2'90	0'40

a = biotite; b = chlorite "ripidolite" type, and c = chlorite-serpentinic mineral from a monzonite; d = "asbestiform" mineral ("serpentine") from a basic alkaline rock; e-f = Ti-augites; g = Fe-pargasitic hornblende from a monzogabbro.

From a nucleus formed of a later-crystal of quartz to the external zone constituted by the chloritic-serpetinic minerals the following petrographic types (according to fig. 4) can be defined.

"chlorite α" → "chlorite β" → "chlorite γ"

The microprobe analysis corroborates our deductions obtained from the optical features on the type and lateral evolution of the chloritic minerals. So, according to the analysis, the chlorite α type (table 2c) corresponds to chlorites rich in SiO_2 and MgO and impoverished in FeO. The chlorite γ type corresponds to chlorites richer in Al_2O, MgO and FeO and more impoverished in SiO_2 than the typical clinochlores (table 2e). The chlorite β type corresponds to intermediate types between α and β ones.

TABLE 2

Microprobe analysis (Villel outcrop)

	a	b	c	d	e
SiO_2	30'60	36'74	34'43	30'40	26'24
Al_2O_3	22'35	11'01	14'25	16'64	18'35
FeO(*)	20'92	10'48	17'69	22'57	26'92
MnO	0'40	0'10	0'45	0'70	0'80
MgO	12'40	28'04	22'95	16'31	11'95
CaO	-	-	-	-	-
Na_2O	-	-	-	-	-
K_2O	0'80	0'67	0'64	1'75	2'78
TiO_2	0'70	-	0'30	0'40	0'55

a = isolated chlorite-biotite; b = chlorite-serpentinic mineral; c-d-e = reaction-transformation serie between chlorite-serpentinic minerals with quartz (after fig. 4).

The evolution from the chlorites α to chlorites γ is characterized by a progressive increase in Al_2O_3 and FeO and a depletion in SiO_2 and MgO.

One of the main deductions obtained from the petrographic and chemical data is that the composition of the chlorite minerals is of them, related with subsequent silicification processes. These may be inferred from the presence of interstitial quartz which gradually and zonally transforms those minerals (figure 4).

ASBESTIFORM FERROMAGNESIANS:

Under this heading is included some slightly defined minerals, whose optical features, appear to correspond more or les with serpentines or to intermediate minerals between "chlorites" and "serpentines" (table 1d). These minerals are associated with the most basic rocks types: monzogabbros-alkaline basic rocks, all of them with great abundance of ferromagnesian minerals, which confer to them a meso-melanocratic appearance.

CLINOPYROXENES:

These minerals, relatively abundant in the monzogabbros and in the basic alkaline rocks, in euhedral crystals according to the microprobe analyses, correspond to Ti-augites (table 1e-f). The rate of crystallization is establised in relation to the rock-type. So in the monzonites the clinopyroxenes are poorly crystallized and associated to chloritic-ferriferous and serpentinic minerals. In the most basic rocks (monzogabbros) in turn this crystallization rate corresponds to highly crystallized minerals.

AMPHIBOLES:

These minerals usually appear in small quantity. In some of the rocks, of monzonitic types, they correspond to pargasitic hornblendes (table 1g).

BIOTITES:

These minerals, although present in all petrographic types, are more abundant in the syenitic-monzonitic rocks, where they are generally associated to chlorites (table 1a). The petrographic studies, about the relationship between the chlorites and biotites from de wall-Keuper materials to the igneous rocks of the centre of the outcrops, point out to different transformation stages from the original chlorites to biotites across intermediate types. In this way this interrelationship should not be understood as a result

TABLE 3

Major chemical elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	50'90	46'47	47'55	50'97	46'04	48'05	52'93	53'82	47'11	42'02	53'90	47'77	46'08	48'97	45'35	41'03	50'71	51'20	54'70
Al_2O_3	15'81	15'38	15'85	16'21	16'24	15'24	16'32	16'87	16'91	17'61	16'36	16'15	15'89	16'06	15'78	16'40	14'01	13'69	15'96
Fe_2O	7'27	6'01	7'23	7'20	7'37	7'25	4'85	3'65	4'53	2'20	5'07	7'51	7'96	6'21	5'31	2'34	3'59	2'21	4'70
FeO	2'93	4'89	3'74	2'98	4'16	4'38	1'70	2'30	3'62	2'90	3'11	4'66	4'67	3'60	2'85	3'10	5'85	6'15	1'59
MnO	0'48	0'44	0'62	0'21	0'40	0'10	0'13	0'11	0'10	0'10	0'34	0'40	0'45	0'38	0'20	0'30	0'14	0'12	0'02
MgO	7'57	9'38	7'54	7'30	8'78	6'53	8'30	8'63	11'34	10'47	5'82	8'46	9'32	8'62	13'15	12'57	7'81	9'04	10'90
CaO	2'83	5'75	5'08	1'84	5'10	4'05	3'93	2'14	2'76	4'04	0'98	0'54	0'65	0'70	2'48	3'40	10'13	7'50	2'66
Na_2O	3'06	2'63	2'42	4'86	2'78	6'18	3'26	2'76	3'16	2'22	2'07	2'00	2'23	1'98	1'62	1'87	3'29	4'35	1'08
K_2O	3'61	2'59	3'90	2'21	2'11	1'64	2'65	3'63	2'56	2'84	7'08	6'15	6'26	7'26	5'43	3'62	0'69	0'84	0'24
TiO_2	1'47	1'92	2'09	2'54	2'15	2'37	1'70	2'16	1'44	1'72	1'59	2'30	1'98	2'00	1'80	1'64	1'00	0'98	0'75
P_2O_5	0'51	0'48	0'45	0'62	0'58	0'65	0'46	0'53	0'53	0'58	0'45	0'51	0'57	0'40	0'35	0'40	0'11	0'17	0'13
H_2O	3'50	3'90	3'50	3'00	3'80	3'60	3'61	3'30	4'83	5'96	3'15	3'60	4'00	3'80	5'20	6'32	2'51	3'46	7'21
CO_2	-	-	-	-	-	-	-	-	0'92	2'01	-	-	-	-	0'40	2'30	-	-	-
SO_3	-	-	-	-	-	-	-	-	0'14	4'31	-	-	-	-	0'10	3'66	-	-	-
Cl	-	-	-	-	-	-	-	-	0'10	1'10	-	-	-	-	-	0'80	-	-	-
TOTAL	99'94	99'84	99'97	99'94	99'51	100'04	99'84	99'90	99'95	100'08	99'92	100'05	100'06	99'98	100'2	99'75	99'84	99'71	99'94

Analysis 1-10 from Camarena outcrop; 1-8 igneous rocks; 9 = border microlitic facies and 10 = Keuper wall material Analysis from Villel outcrop; 11-14 igneous rocks; 15 = border microlitic facies and 16 = Keuper wall materials Analysis 17-19 from an ophitic outcrop of Pyrenean zone (Lago, 1980); 17 = ophitic rock (average of 27); 18 = border microlitic rocks (average of 6) and 19 = Keuper wall materials.

of some alteration processes, but as a particular petrogenetic stage where both minerals coexist within a prograde-transformation process.

Chemical features and some petrological implications

Some important considerations of petrological meaning can be deduced from the chemical analysis (table 3 and diagrams of fig. 9), as well as from the petrographic data.

— Relatively low ratios of SiO_2 and high of Al_2O_3 in relation to the data deduced from the petrographic studies.

— High ratios of MgO.

— High ratios of Fe_2O_3 in relation to FeO, and so on

From diagram analysis two evolutive geochemical trends, that correspond to two different structural outcrops of igneous rocks, can be differentiated: Villel and Camarena type.

The Villel outcrop exhibits a more continous geochemical evolution than the Camarena one. This differentiation can be attributed to their different petrological-structural features in both outcrops. The Villel outcrop constitutes in general a single continous mass of igneous rocks, whilst in Camarena as a consequence of its stratiform configuration many petrographic-geochemical types can be repeatedly present.

As it can also be observed there are notable differences between the rocks the subject of the present paper and the ophitic ones. These differences have already been noticed in field and in petrographic studies.

From evolutive petrographic and chemical data from the Triassic wall-materials to dominant central igneous facies rocks it is possible to deduce the probable sedimentary heredity of some of the features.

Data on the composition of the Keuper materials, show that sediments exhibit high rates in magnesium indicated by amounts between 12 and 14.8 of MgO, which is mainly derived from the richness in minerals of the chloritic types.

The high ratio of Fe_2O_3/FeO, that defines these rocks as oxided, according to the chemical analysis, could be a consequence of the chemical nature of the wall-materials and/or the "oxidation processes", that probably took place during the "building" of the igneous-facies rocks.

As far as we know as a result of the chemical analysis, the Triassic materials contain abundant iron and titaniferous minerals, as ilmenite and haematite.

The geochemical evolution from Keuper wall-materials to the igneous rocks, together with some petrographic deductions, seem to indicate that the oxidized feature of igneous rocks does not correspond to a hypergenetic-alteration process, but to the primary character formed during the petrogenesis of these igneous rocks.

Other elements, relatively abundant in the igneous rocks and that could be indicators of a sedimentary heredity, are TiO_2 and P_2O_5. The former, mainly contained in ilmenite minerals (abundant in all the igneous facies rocks) is also frecuently associated to iron minerals in the Triassic-wall sediments. The P_2O_5 in apatites of igneous rocks could be in great part formed by the remobilization and transformation of phosphorous components, nowadays present in some Muschelkalk-Keuper levels.

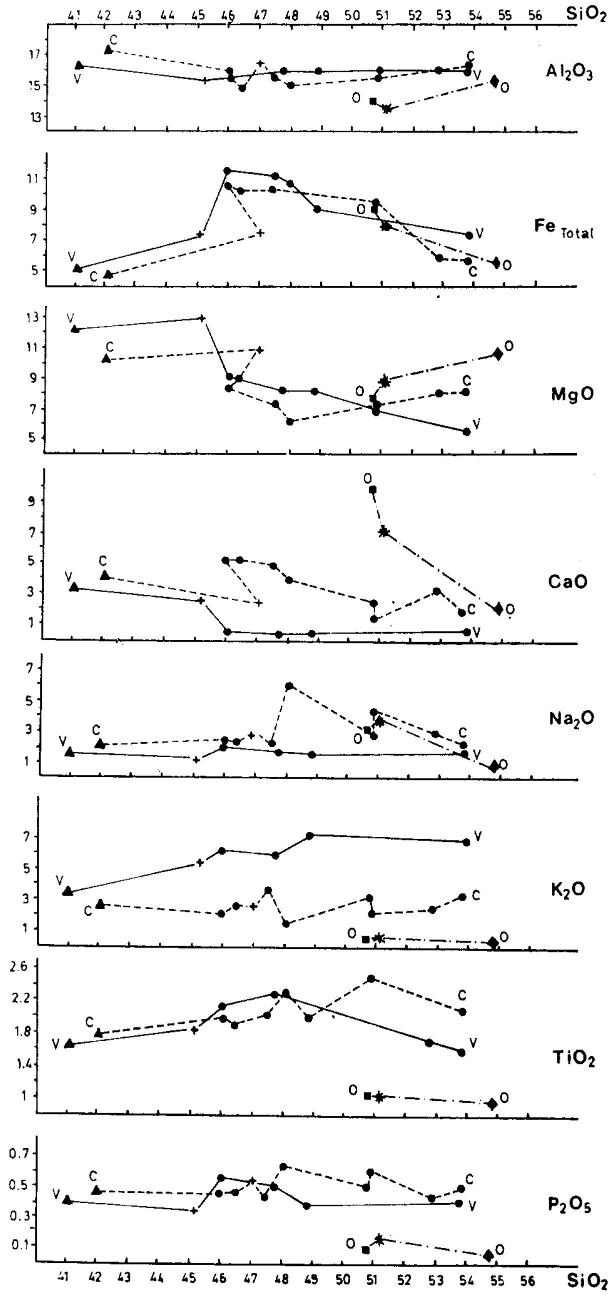

Fig. 9.—Plots of oxide percentajes against SiO_2. C=Camarena sub-stratiform outcrop; V=Villel sub-intrusive outcrop; O=Ophitic rocks from Pyrenean zone. Solid circles=Igneous facies rocks; Solid triangles=Keuper wall materials; Crosses=Border-microlitic facies; Solid square=Ophitic rocks; Solid diamond=Keuper wall materials of ophites; Stars=Border microlitic facies in ophites.

The relative low ratio of SiO_2 and high of Al_2O_3 in many rocks could be explained by the constant presence in all the petrographic types of abundant argil-micaceous minerals, which we interpreted as materials of sedimentary origin more or less transformed during the processes that took place in the origin of the igneous facies rocks.

These argil-micaceous minerals, that appear to be little transformed, have remained as residual ones probably because the low physical gradients resulted in the fact that these "impurities" were not expelled out of the new minerals (mainly feldspars).

This apparent anomaly can be explained because these rocks have not reached the petrological equilibrium. So the quartz, in the syenitic rocks, is associated with intersticies and is almost always reacting with the ferromagnesian minerals (chlorite-sepentines) originated in the prior stages.

This lack of petrological equilibrium could be a consequence of the type and evolution of the petrogenetic process. So our first data, from the field to petrographic-geochemical ones, seem to indicate that the processes, that formed the igneous rocks were developed in various stages that were active for a long time.

These processes of long-term-evolution deduced from field and petrographic observations within separate types of rocks (from monzogabbros to granites) are also observed within the same petrographic rock-type so, for example, in a monzonite it is possible to establish several mineralogical crystallization sequences, as well as mineralogical transformations induced by the contribution of subsequent allocthonous chemical elements, that we supposed similar to those ones which later formed the granitic and hornfel rocks.

On the other hand in almost all the igneous rocks, mainly in those of later origin, it is possible to state a lack in the petrological equilibrum from the textural-mineralogical and chemical data, for example through the existence of anisotropic transformation sequences, that include from subsaturated to saturated minerals. So on a microscopic scale, it is possible to observe over saturated zones (quartz-zones) and some others with subsaturated minerals formed by serpentinic-chloritic minerals. This apparent petrographic-chemical anomaly is more evident in the hornfel rocks, where there exists, on a microscopical scale, zones with quartz + sillimanite + feldspars and others with spinel + kornerupine + cordierite.

All these last observations together with the field, petrographic and chemical data on the studied igneous rocks facies seem to indicate that the origin of these rocks is a consequence of petrological transformation processes that took place between the suitable Keuper materials and metasomatizing silica-alkaline elements of endogenetic origin.

The petrological-mineralogical transformations that took place between the silica-alkaline metasomatizing elements and the suitable wall-materials of the Keuper, as well as the origin of the physical gradients involved during these processes, are presently being studied.

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