

# RESIDUAL CIPOLINO: END-PRODUCT OF CALCAREOUS ROCKS IN REGIONAL METAMORPHISM

By

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**Abstract.** Intercalations of banded rocks of quartzitic appearance, consisting of an equigranular mosaic of quartz and basic plagioclase with interspersed large crystals of diopside, hornblende, and garnet, are fairly common in high-grade metamorphic terranes. These rocks, variously named plagioclase-granulites, diopside-granulites, calc-silicate granulites, feldspathic pyroxenites, silicated carbonate rocks, etc., are derived from *normal* limestones and dolomites with average contents of impurities, from which  $\text{CaCO}_3$ ,  $\text{MgCO}_3$ , and, possibly, minor potassium have been leached in the course of metamorphism. Small amounts of Ca and Mg, reacting with the impurities, gave rise to Ca-Mg-silicates. As these rocks have developed from marbles, with an intermediate stage of Ca-Mg-silicate bearing marbles (cipolinos), into calcite-free Ca-Mg-silicate rocks, the name 'residual cipolino' is proposed for such rocks.

## Description and field occurrence

During fieldwork and excursions in France, Turkey, Greece, Austria, and Norway from 1954 to 1964, the writer regularly came across banded, quartzite-like intercalations in basement rocks (augen gneisses or anatexites, as well as non-migmatitic gneisses of amphibolite-facies). These tough, greenish or bluish rocks are generally well-banded, even amid nearly structureless, nebulitic gneisses. One can hardly doubt their sedimentary origin, as may be judged from Figs. 1, 2 and 3. A close association with patches or bands of marble was occasionally observed. When found between augen gneisses or anatexites, they were always separated from these by a thin layer of fine-grained plagioclase gneisses rich in biotite.

A sedimentary origin is accepted as certain by all the authors who have described these rocks in the field. To BARTH (1936), the sedimen-



Fig. 1. Lens of residual cipolino in banded marbles, Kaz-Dağ, Turkey. For composition of lens, see Table 1, no. 12.

metamorphosed sediments.' HEIM (1952) stated: '... the oblong shape of the hornfels<sup>1</sup> and the presence of an intercalated band of marble point to the same conclusion.' (i.e., a sedimentary origin). Important evidence concerning the sedimentary origin of these rocks comes from India, where workers agree unanimously on this point, e.g.

<sup>1</sup> Actually a lime-silica hornfels.

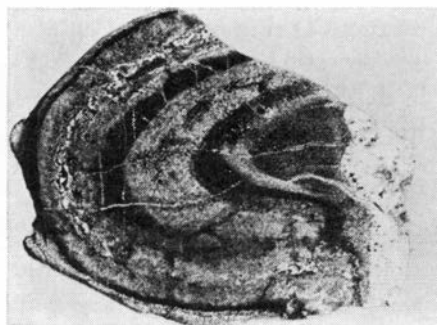


Fig. 2. Polished slab of folded residual cipolino, cut by small pegmatite vein. Dôme de l'Agout, Southern France. Size: 11.5 cm by 8 cm.



Fig. 3. Folded residual cipolino embedded in cordierite-bearing anatectic gneiss-granite. Dôme de l'Agout, Southern France.

tary origin was so obvious that he simply refers to 'the original sediment'. BÉLAND (1961, Fig. 1b) shows a contorted band of carbonate rock in gneisses; within it, narrow bands of 'residual cipolino' (BÉLAND's highly silicated carbonate rock) are to be seen. WHITE (1959) wrote: 'The association of calc-silicate rocks with relatively pure marbles at both Tungkillo and Milandella, and the presence of uniform banding that is parallel to the bedding in the adjacent quartzo-feldspathic schists at Tungkillo, leave no doubt that these rocks are

BAGCHI, who wrote (1952): '... the purer sediments, richer in Ca, however, were recrystallized to diopside-granulite and calc-granulite, etc.'

In the Dôme de l'Agout, Southern France, which is a domed structure of augen gneisses and anatexitic granite, the whole surrounded by micaschists, the writer studied the residual cipolinos in different metamorphic facies, from the biotite-staurolite subfacies, through the kyanite-muscovite and the sillimanite-almandine subfacies, downward into the cordierite-biotite subfacies. With increasing grade of metamorphism, the following trend becomes visible:

- Marbles,
- Marbles with pronounced effects of solution along stylolitic seams, with concomitant concentration of impurities,
- Marbles with Ca-Mg-silicates (cipolinos),
- Ca-Mg-silicate rocks with interstitial calcite,
- Calcite-free Ca-Mg-silicate rocks (residual cipolinos).

It should be stated, however, that this transition could not be followed in the field along one band, but that it is the trend which different, though comparable bands show with increasing depth. Fairly high in the series, Ca-Mg-silicates can occasionally be found, while even down to the deepest levels exposed, a few relatively pure marble bands and patches still persist.

Under the microscope, residual cipolinos show a mosaic of equigranular quartz and basic plagioclase with interspersed large crystals of diopside-hedenbergite, amphibole, and garnet, often displaying a sieve-texture (poikiloblasts). Potash feldspar is absent, or when present is clearly of late origin, introduced into the rock after the crystallization of all the above-mentioned minerals, which it then encloses in poikiloblastic habit. In the upper part of the amphibolite facies, these rocks may carry a mineral of the epidote-zoisite-clinozoisite group, which in this paper is termed 'epidote', after FRANCIS (1958), in association with a more acid, rather than a basic plagioclase. In addition to these minerals, scapolite and vesuvianite have been found and, rarely, wollastonite. Typical accessory minerals include titanite and pyrite/pyrrhotite. The plagioclases are only rarely zoned, and are mostly untwinned or twinned polysynthetically. They may contain as much as 96% anorthite.

Tables 1 and 2 present a number of mineralogical and chemical compositions of typical residual cipolinos.

Table 1. *Mineralogical composition of some residual cipolinos*

Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
quartz	19.0	20.5	36.1	33.4	51.6	0.8	—	47.7	3.9	33	0.9	23.4	11	5	12	—	27.5	3.0	18.3
k-feldspar	—	—	—	—	—	—	—	—	—	—	7.5	1.0	—	—	—	—	—	—	—
plagioclase	35.2	49.9	40.0	40.8	26.6	88.0	29.9	38.9	44.4	15	50.5	36.0	35	31	33	40	15.2	—	36.1
garnet	—	3.0	—	8.1	4.0	—	51.0	0.8	36.7	1	—	5.7	35	7	—	—	—	—	8.5
biotite	—	—	—	—	—	—	—	—	—	—	—	4.1	—	x	—	—	x	—	x
hornblende	21.8	22.2	3.3	3.8	13.5	7.3	—	10.8	—	—	3.8	3.6	—	3.5	31	25	18.2	—	9.2
diopside	19.9	—	13.3	25.0	—	—	8.8	2.0	11.9	48	29.2	17.3	7	30.5	21	16	14.3	60.1	18.0
'epidote'	—	1.0	—	2.5	—	—	10.3	—	3.1	3	—	—	—	20.5	—	17	7.3	31.0	4.3
scapolite	—	—	—	—	—	—	—	—	—	—	3.8	5.2	8	—	—	—	15.7	—	2.7
calcite	—	—	—	—	0.5	0.8	—	—	—	—	—	0.3	—	1	—	—	—	—	x
titanite	1.8	0.4	3.8	1.1	2.0	3.1	—	—	—	1	2.9	1.6	3	1	2	—	0.9	3.0	1.6
opaque minerals	2.3	4.2	3.5	1.7	1.4	—	—	—	—	x	1.6	1.8	1	0.5	—	2	0.9	2.9	1.3

— absent                      x present in rock, but not encountered on counting lines

- 1-4 Dôme de l'Agout, France (SCHULING 1960)  
5 Dutchess County, New York (BARTH 1936)  
6-9 Simultala, Bihar, India (BOSE 1957)  
10 New Hampshire, U.S.A. (CHAPMAN 1952)  
11, 12 Kaz-Dağ, Turkey (SCHULING unpubl.)  
13 Shawinigan Area, Quebec, Canada (BÉLAND 1961)  
14 Vegarshei, Norway (SCHULING unpubl.)  
15 Sierra de Guadarrama, Spain (HEIM unpubl.)  
16 Madagascar (CUP unpubl.)  
17 Naxos, Greece (SCHULING unpubl.)  
18 Theussenbach, Koralpe, Steiermark, Austria (SCHULING unpubl.)  
19 Average of 18 residual cipolinos

Note: the average composition of the plagioclases in sample nos. 4, 5, 11, 13, 15 and 16 is Ab 28 An 72

Table 2. *Chemical composition of 7 residual cipolinos. Nos. refer to samples of Table 1*

Sample no.	1	2	3	4	5	17	18	A	B	C
SiO <sub>2</sub>	64.0	63.0	61.0	66.0	72.1	62.0	48.3	62.3	57.7	59.9
TiO <sub>2</sub>	0.7	1.0	0.9	0.7	1.4	0.5	1.13	0.9	0.8	0.7
Al <sub>2</sub> O <sub>3</sub>	19.0	16.5	18.5	17.0	12.8	14.0	15.1	16.1	13.6	9.4
Fe <sub>2</sub> O <sub>3</sub>	1.8	0.8	1.6	1.0	0.4	3.2	1.9	1.6	0.5	} 6.2
FeO	3.5	3.7	4.0	2.9	4.2	2.9	6.2	3.9	} 8.6	
MnO	0.22	0.21	0.36	0.24	0.45	0.19	0.18	0.26		} 2.5
MgO	1.8	1.8	1.6	1.3	1.0	2.8	6.2	2.4	} 12.7	
CaO	11.0	6.1	11.5	10.2	7.1	10.4	17.8	10.6		} 16.4
K <sub>2</sub> O	1.5	2.5	0.4	0.5	0.1	0.9	1.25	1.0	—	
Na <sub>2</sub> O	1.0	1.1	0.9	1.4	0.3	3.1	0.55	1.2	2.1	0.7
Cr <sub>2</sub> O <sub>3</sub>	nd	nd	nd	nd	nd	nd	0.078			

A: Average of 7 residual cipolinos (columns 1, 2, 3, 4, 5, 17 and 18)

B: Computed chemical composition from mineralogical composition of 17 residual cipolinos (nos. 1–17 of Table 1)

C: Computed average chemical composition of residual cipolinos as derived from the average limestone of Clarke (see Table 3)

Analyst: v.d. Weyden (nos. 1, 2, 3, 4, 17, 18)

Klüver and Ellestad (no. 5)

The analyses 1, 2, 3, 4, 17, 18 have been carried out by X-ray fluorescence and flame-photometry, no. 5 by wet methods. Fe<sub>2</sub>O<sub>3</sub> was analysed separately by wet methods in nos. 1, 2, 3, 4, 17, and 18, MgO by wet methods in nos. 1, 2, 3, 4, and 17, by X-ray fluorescence in no. 18.

### Origin of Residual Cipolinos

Most petrologists will readily agree that rocks of mineralogical compositions as given in Table 1 are of metasedimentary origin, as was proven from the field occurrence of these rocks; therefore, the problem of origin presents itself in an unambiguous way, i.e., to find a sediment which corresponds to this group. As a second prerequisite to this, as yet hypothetical, sediment needs to be a common sediment, encountered regularly in a geosynclinal series, and preferably in association with limestones. If the residual cipolino mineralogical composition is roughly according to oxide percentages (Table 2, note B), and if it is admitted that Ca and Mg would be present almost exclusively as

carbonates in the original sediment, a composition is arrived at which is highly unusual for a sediment. One could describe it as a sandy, dolomitic, ferruginous marl, with high concentrations of Ti and S. This is hardly the common sediment we were led to expect, and even from this sediment we have to admit leaching of  $\text{CO}_2$  (and K) during metamorphism in order to achieve correspondence.

Substantial leaching of some elements is required if we are to arrive at residual cipolinos by starting with *normal* limestones. To investigate this, a kind of norm-calculation was used, starting with the average limestone of Clarke (average of 345 limestones).

Before concluding anything from Table 3, note that the relative amounts of diopside and quartz have no precise significance; there may be very little diopside and much quartz, or much diopside and no quartz at all, depending upon the rate of escape of  $\text{CaCO}_3$  *v.*  $\text{MgCO}_3$  and the rate of escape *v.* crystallization, which are unknown. That  $\text{Al}_2\text{O}_3$  is first used to form normative plagioclase instead of potash feldspar agrees with NIEUWENKAMP (1956) who states that Ca will first form plagioclase and take along any sodium present, whereas potassium will not enter into feldspars unless calcium is present in insufficient amounts. Water may cause hornblende to substitute for diopside, and, if the degree of metamorphism does not permit crystallization of a basic plagioclase, we may find epidote and acid plagioclase instead.

In the example chosen, the resulting rock would have the following composition (wt %):

quartz	22.0	
albite	6.0	
anorthite	22.3	ab 21 an 79
diopside/hedenbergite	45.9	
titanite	1.7	
pyrite/pyrrhotite	2.1	

Such a rock is certainly typical of the group of residual cipolinos. It is indeed hard to accept leaching so extensive that only 8.7% by weight would remain, on the average, of an original limestone. However, if we bear in mind that  $\text{CO}_2$  (and probably K) must leave, and that these rocks constitute the end member of a series in which a

Table 3. 'Norm-calculation' of a residual cipolino from the average of 345 limestones of Clarke

	wt. %	mol. %	FeS + FeS <sub>2</sub>	titanite	albite	anor- thite	diopside	quartz	escapes	composition of residue		
										A	B	C
SiO <sub>2</sub> .....	5.19	4.30	—	0.04	0.24	0.70	1.72	1.60	—	4.30	5.19	59.9
TiO <sub>2</sub> .....	0.06	0.04	—	0.04	—	—	—	—	—	0.04	0.06	0.7
Al <sub>2</sub> O <sub>3</sub> .....	0.81	0.40	—	—	0.04	0.36	—	—	—	0.40	0.81	9.4
Fe <sub>tot.</sub> ....	0.54	0.37	0.08	—	—	—	0.29	—	—	0.37	0.54	6.2
MnO ....	0.05	0.03	—	—	—	—	0.03	—	—	0.03	0.05	0.6
CaO.....	42.61	37.78	—	0.04	—	0.36	0.86	—	36.52	1.26	1.42	16.4
MgO.....	7.90	9.53	—	—	—	—	0.54	—	8.99	0.54	0.45	5.1
Na <sub>2</sub> O.....	0.06	0.04	—	—	0.04	—	—	—	—	0.04	0.06	0.7
K <sub>2</sub> O .....	0.33	0.17	—	—	—	—	—	—	0.17	—	—	—
S .....	0.09	0.12	0.12	—	—	—	—	—	—	0.12	0.09	1.0
CO <sub>2</sub> .....	41.85	47.22	—	—	—	—	—	—	47.22	—	—	—
Total.....									92.90	7.10	8.67	100.0

A: Mol % of residue

B: Wt. % of residue

C: Wt. % of residue, recalculated to 100% (wt.). This is the composition of material left, after escape of CaO, MgO, CO<sub>2</sub> and K<sub>2</sub>O, and is also given in column C of Table 2.

strong solution of  $\text{CaCO}_3$  (not only  $\text{CO}_2$ ) is manifest along stylolite seams, the view developed here seems more acceptable.

There are, in any case, only two additional possibilities, both far from promising:

1. To seek a sediment which is closer in composition to that of the residual cipolinos, and thereby eliminate the need for extensive leaching.
2. To admit that these rocks originated by influx of Si, Al, Fe and Mg to a limestone band ('skarn-formation' in regional metamorphism).

The first possibility has been discussed above, with conclusion that it is unacceptable because such a parental sediment is either non-existent or extremely rare. It should be noted, however, that small variations in the content of impurities in the original carbonate rock may produce large variations in the resulting residual rocks. This is brought about by a process of relative enrichment of the more insoluble elements, which become major elements through leaching of the carbonates. In this way the variations of the original limestones may be reflected in the extremely variable mineralogical compositions of the residual cipolinos.

The writer considers the fine-grained plagioclase gneisses, rich in biotite, which always surround the residual cipolinos and separate them from the surrounding gneisses, to be the reaction product of the migmatitic gneisses and the calc-silicate rocks. A similar origin was proposed by BARTH (1928) for biotite-rich plagioclase gneisses near Kristiansand, Norway: 'skarns'<sup>2</sup> react with 'granitic' material to form biotite gneisses. This interpretation is supported by a field observation of the writer in Southern France, where at the border-zone of a small cross-cutting vein of mobilized migmatitic gneiss-material, a small zone of this fine-grained, biotite-rich gneiss had formed, passing laterally into the residual cipolino.

As a whole, residual cipolinos seem to form fairly well-closed systems with regard to influx of material. They may even because of their impermeable character act as a tight barrier around enclosed patches and bands of relatively pure marble, and prevent their development into residual cipolinos. The association of relatively pure

<sup>2</sup> Residual cipolinos of the present paper.



marbles and residual cipolinos does not indicate a different starting composition, but only an arrested stage in the development of the residual cipolinos. The formation of this rock-type should be viewed as an end-product of *normal* limestones, with *normal* amounts of impurities from which the carbonates were expelled during metamorphism. It is possible that the scarcity of carbonate rocks in Precambrian metasedimentary series is caused in part by this process of leaching of the carbonates, leaving only narrow and inconspicuous bands of residual cipolinos.

### Definition and nomenclature

The author holds it admissible to use two kinds of definition and name for one object: the one linking it to direct observation (descriptive definition), and the other to its inferred mode of origin (genetic definition). Here, the group of rocks under consideration was given the name 'residual cipolinos', which has a genetic connotation. This was done because the existing, purely descriptive names lead to confusion. The rocks have been termed plagioclase-granulites, calc-silicate granulites, diopside-granulites, etc. To avoid confusion, it is desirable to retain the term 'granulite' only for rocks which have crystallized in the granulite-facies of metamorphism. Granulite should not be used as a descriptive term to denote, in a loose way, a kind of metamorphic (equi-) granular texture. As most of the residual cipolinos studied by the writer crystallized in the amphibolite-facies, to which they need not be confined (BAGCHI 1952 and MUKHERJEE 1955 describe them from granulite-facies), any denotation in terms of metamorphic facies should be left out of the definition. A general descriptive term for the group might be 'calc-silicate leptynite', if we consider leptynite as denoting any metamorphic rock which is composed mainly of quartz and feldspar (as proposed by COGNÉ and VON ELLER 1961). Another possibility involves the use of GOLDSMITH'S (1959) term 'calc-silicate granofels'. The writer does not wish to propose either name for the moment, in order to leave the way open to other suggestions.

Residual cipolinos, as contrasted with cipolinos (which are Ca-Mg-silicate-bearing marbles), contain at the most a small amount of interstitial calcite; they are metamorphic rocks of quartzitic appearance and consist of an equigranular mosaic of quartz and basic plagi-

clase with interspersed, large crystals of diopside and/or hornblende and/or garnet. They are derived from *normal* limestones and dolomites from which  $\text{CaCO}_3$  and  $\text{MgCO}_3$  were expelled in the course of metamorphism, leaving only sufficient Ca and Mg to combine with the impurities as Ca-Mg silicates.

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