

WEATHERING AND GEOCHEMICAL BEHAVIOUR OF THE ELEMENTS OF ULTRAMAFIC ROCKS IN NEW CALEDONIA

by J. J. Trescases

ORSTOM, New Caledonia

SUMMARY

Since Miocene time the ultramafic rocks in New Caledonia have been subjected to an insular tropical to subtropical climate.

As a result of intense erosion with lateritic weathering during Mio-Pliocene time, the topography has been levelled off; small rocky ridges dominated the vast foothill areas and the more or less swampy lowlands. The low areas were thus 'iron-capped'. The Plio-Quaternary tectonic activities uplifted, unbalanced, and fractured this peneplain surface, causing once again erosion and morphology inversions, and the 'iron-capped' relics dominated mesas. New foothill surfaces appeared, as a result of destruction of the 'iron-capped' lateritic areas, and these were in turn 'iron-capped' also.

In well-drained areas (mesas and slopes), weathering appears as ferric gel and antigorite (especially in the dry season), mechanical fragmentation, and formation of laterites of the granulometric fraction under 50μ (especially in the wet season). If the slope is steep, weathering is obstructed by erosion. On the mesas, however, laterite continues to form with total leaching of magnesium and silica. Iron concentrates on the spot as goethite and hematite, in places forming concretions. Chrome and aluminium (chromites) are also residual. Part of the residual nickel, cobalt, and manganese precipitate together as oxidized concretions (lateritic nickel and cobalt ore). The greater part of the nickel is concentrated at the interface between the weathered zone and the fresh rock below, along with dissolved silica and magnesia, as antigorite, talc, chlorite, or mixed gels (garnieritic nickel ore).

In poorly drained areas (foothills), the silica migrating from high areas combines with lateritic materials resulting from the destruction of these surfaces, leading to the formation of nickeliferous nontronites. In these environments, the weathering of the fresh peridotites also results in nontronites. The magnesia migrates by underground and river waters and precipitates only near the seashore, as giobertite.

Thus lateritic weathering corresponds throughout the countryside to a true chromatography of the ions, concentrations (eventually economical) of the elements being distributed through the topographic profile according to their respective mobilities.

INTRODUCTION

The New Caledonian ultramafic rocks were emplaced in the Oligocene, or perhaps at the end of the Eocene (Routhier, 1953). Some peridotitic pebbles are interbedded in Miocene calcarenite beds (Routhier, 1953)—the earliest known evidence of their erosion—but the first signs of lateritic weathering (fragments from iron crusts) seem to be more recent, and are associated with the probably Pliocene clay deposits, of mangrove type (Gonord & Trescases, 1970). For several

millions of years these bodies of rock have been subjected to an insular tropical to subtropical climate—the climate has changed several times, especially at the time of the Quaternary glaciations, with some dryer and hotter periods.

GEOMORPHOLOGY

The rocks are very susceptible to weathering, because silica and magnesia, their main components, are easily dissolved by meteoric waters. During the Mio-Pliocene period, weathering and erosion reduced the topography. This stage continued for a long time, and the result has been an extensive flattened surface: from north to south of New Caledonia, it is possible to find some remains of it on all the peridotitic terrain, and in places on other rocks (Dogny Plateau). The authors who have studied the geomorphological evolution of New Caledonia (Davis, 1925; Routhier, 1953; Avias, 1953; Wirthmann, 1965) called it the *Peneplain*.

The manner of formation of this peneplain has been most unusual, because the tropical climate is very aggressive and the peridotites are quickly weathered: the result of these two combined factors is that in New Caledonia, the ultramafic rocks tend to behave as soluble rocks. Moreover, these rocks are very easily faulted: the stressed serpentine promotes sliding of blocks against one another, and at every scale of observation the peridotitic bodies show a very dense network of joints and faults. The nature and structure of these rocks has given rise to a true karst terrain, with subterranean drainage, sinks, and depressions, aligned along the fracture system.

The lateritic weathering leaches silica and magnesia, and leaves a residue mainly of iron hydroxides (laterite). These residual materials are attacked by erosion, and removed from high to low ground. As the topography is flattened out, the small depressions (dolines) enlarge and join together (analogous to the 'poljes' in the calcareous karsts), until they are separated only by low residual ridges of outcropping rock. All these low areas, filled by detrital ferruginous material (transported only a short distance), can thus develop an iron capping: in fact the variations of groundwater level in these materials causes repeated solution and precipitation of the iron, which cements the detrital particles together. Such a terrain can be seen in the extreme south of New Caledonia, where a peridotitic karst is well developed and the peneplain topography is still preserved. The ironstone cap protects the underlying materials against erosion: when the weathering continues, the former ironcrusted depressions, by differential erosion, became the dominating features of the terrain, in the form of plateaux—a process of inversion of relief.

The Plio-Quaternary tectonic activity uplifted, tilted, and fragmented this peneplain surface: its relics, which are practically the only places where a solid ironstone cap can be seen intact, now constitute high points (except in the extreme south of the island). This uplift caused faulting of the underlying formations (or reactivation of a former network of fractures): the peneplain was carved into blocks, bounded by large faults. These faults are mainly transverse to the long axis of the island: most of them strike 170°E or 20°E, but some are aligned at 130°E, like New Caledonia.

The central part of the island is more uplifted than the ends; the elevation of remnants of the peneplain is more than 1000 m in the central part, and only 300 m at the extremities. Some parts are even downthrown, for example the channel

between New Caledonia and the Isle of Pines. During this uplift, a new drainage system was established, the former closed sedimentary basins opened, and rivers formed to drain these filled depressions. Naturally, this river network was controlled by the alignment of the dolines or rocky ridges, which themselves were tectonically controlled. This river system is nearly the same as the present one.

A new surface was formed as a result of destruction of the peneplain, about 150 to 400 m below the peneplain level. This surface was certainly formed by a different process from the peneplain, because a well-marked river system was now established. The uplift ended the state of equilibrium of the peneplain, and strong erosion caused the accumulation on the foothills, by alluvial and colluvial processes, of a large mass of detrital ferruginous materials, derived from the weathering mantle of the peneplain. The conditions generally were not suitable for the formation of iron crust, either because the period of stability was not long enough, or because the morphological environment was not favourable (the sedimentary basins were no longer closed). The peneplain relics now constitute a narrow summit plateau, which forms a dividing ridge between the east and west coasts. The remains of the second surface (called Intermediate Level by Wirthmann, 1965), consist of flattish summits on the transverse secondary ridges which separate the river basins.

Tectonic uplift continued and even intensified; new piedmont surfaces appeared, about 500 to 600 m below the Intermediate Level (this third surface is called 'Old Piedmont'—Trescases, 1969). The third surface is always in piedmont position, but it is strongly notched by the present watercourses, because uplift is still going on (Launay & Recy, 1969; Baltzer, 1970). Some of the piedmont areas are encrusted with iron, but this phenomenon is very localized.

WEATHERING AND GEOCHEMISTRY

Chemical erosion continues under each surface after its formation. The oldest weathering layers are removed by erosion (with the exception of some very massive iron crusts) and, even on the oldest surfaces, the weathering profile is Quaternary, and its basal part is in equilibrium with the present climatic dynamics. Rock and climate being essentially homogeneous, in the New Caledonian ultramafics the fundamental factor in weathering is the morphological environment. This factor acts by the intermediary of the geochemical characteristics of the terrain upstream of the weathering profile studied, and by the drainage value at this point. These two elements combine: the well drained zones are mainly on high ground, that is, on the plateaux of the oldest surfaces, and on the steep slopes intersecting them; the poorly drained areas are on the surviving piedmonts and on the areas of sedimentation (depressions, lowlands, confined environments).

Well drained areas

Plateaux

A schematic cross-section of the plateaux is given in Figure 1. The plateau is an iron-capped relic from the peneplain (first surface). A typical weathering profile has been sampled throughout by boring, to the south of Kouaoua village

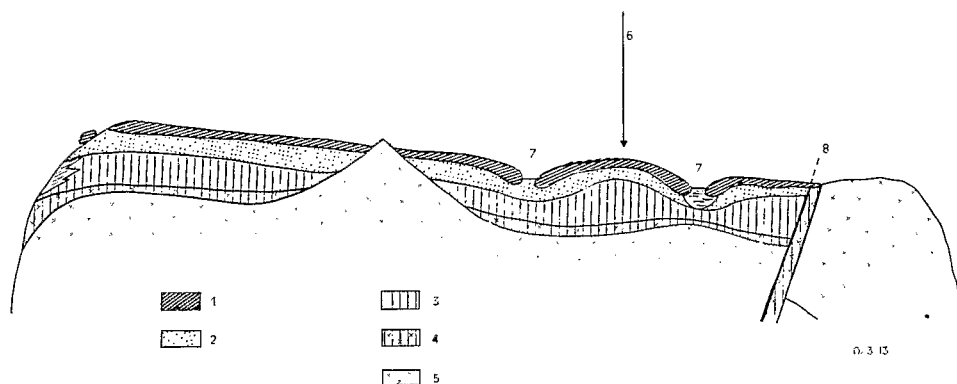


Fig. 1. Theoretical section of the well drained areas (ironstone capped plateau).

- | | |
|----------------------------|---|
| 1 Iron crust | 5 Fresh peridotite |
| 2 Granular laterite | 6 Sampled bore |
| 3 Fine-grained saprolite | 7 Doline |
| 4 Coarse-grained saprolite | 8 Recent fault with mineralized breccia |

(East Coast), on the large ironcrusted plateau of Dahi-Me Aïu, about 500 m west of the top of Me Aïu. The profile shows the following weathering levels:

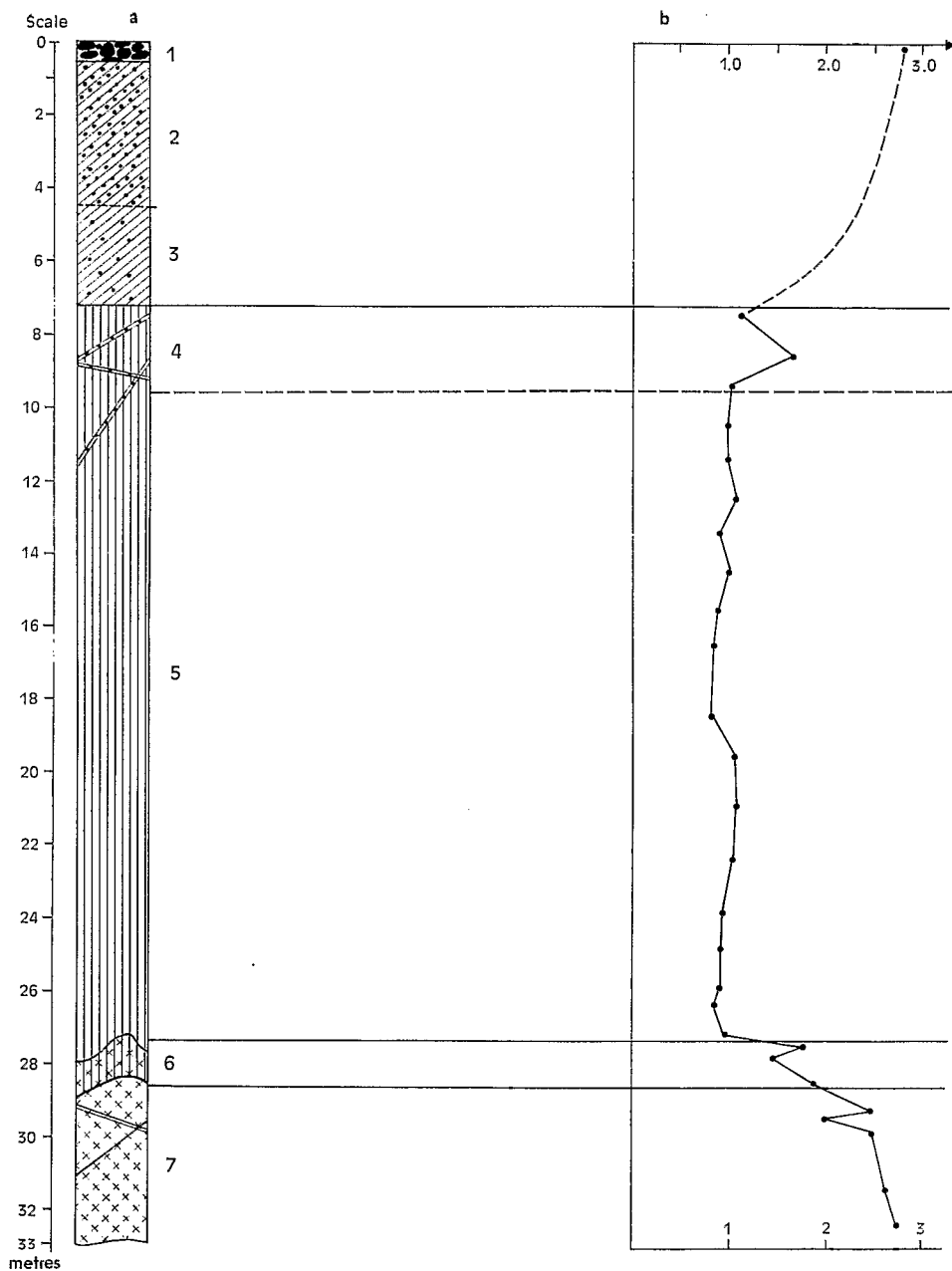
- Ironstone cap
- Granular red laterite (ironshot soil)
- Weathered rock, with recognizable structure, altered to iron hydroxides, fine-grained (fine-grained saprolite)
- Fresh peridotite.

Figures 2 and 3 illustrate the description of the profile, and the vertical evolution of grain-size distribution and bulk density. The chemical behaviour of the elements during weathering is shown on Figure 4, and the geochemical balance of the weathering is sketched on Figure 5, on the basis of isovolumetric calculation, applied to the layers where the rock structure is recognizable (saprolite levels).

From bottom to top the profile is as follows (see also Table 1):

Bedrock (Guillon, 1969, 1971). In this case bedrock is a dunite, with a small proportion of orthorhombic pyroxene (enstatite) and chromite; the magnesian olivine (about 90% forsterite) is very serpentinized. The nickel content is relatively high. The rock is much fractured, and its joints are filled by secondary quartz crystals, by garnierite, or by coarse-grained saprolite. The most common peridotite in New Caledonia is harzburgite, which has only a little more enstatite and a little less chromite than the dunite.

Coarse-grained saprolite. This is a heterogeneous layer, brownish-yellow to greenish-brown in colour, with many coherent fragments (pebble, granule, and sand size) of serpentinized rock. At the bottom of this layer the chemical and mineralogical composition is the same for every grain size fraction: talc, chlorite, antigorite, mixed gels (ferric gel and silica gel). Weathering begins by mechanical fragmentation; expelled from the mineral network, the iron is oxidized and precipitated; secondary silicates are formed. Towards the top of this layer the coarsest grain size fraction (above 2 mm) still resembles that of the bottom, but the finest fraction (under 50 μ) is greatly enriched in iron (goethite) because ferrallitic weathering has begun.



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Fig. 2. a—Description of the profile (plateau). b—Bulk density.

- | | |
|---------------------|----------------------------|
| 1 Ironcrust | 5 Fine-grained saprolite |
| 2 Granular laterite | 6 Coarse-grained saprolite |
| 3 Plastic laterite | 7 Fresh peridotite |
| 4 Crushed saprolite | |

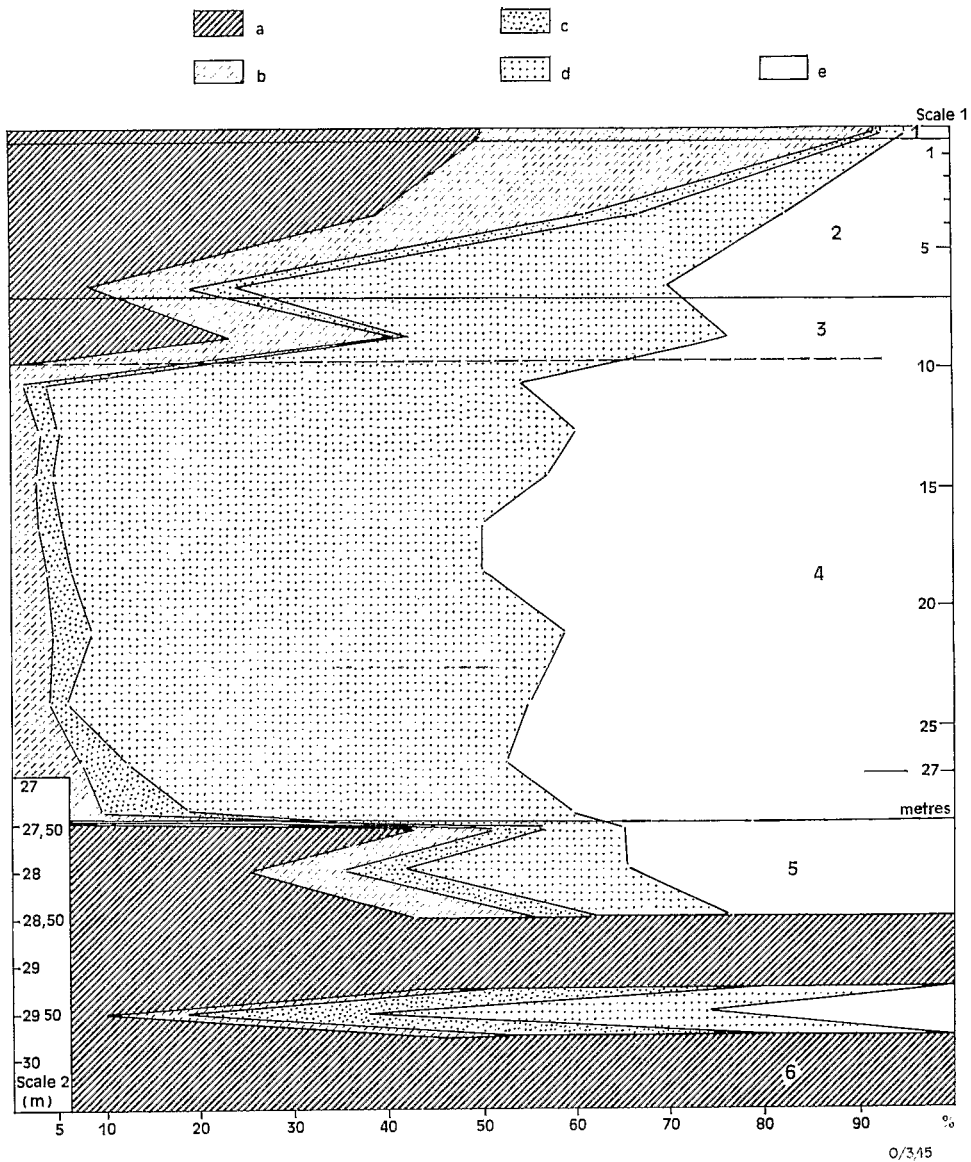
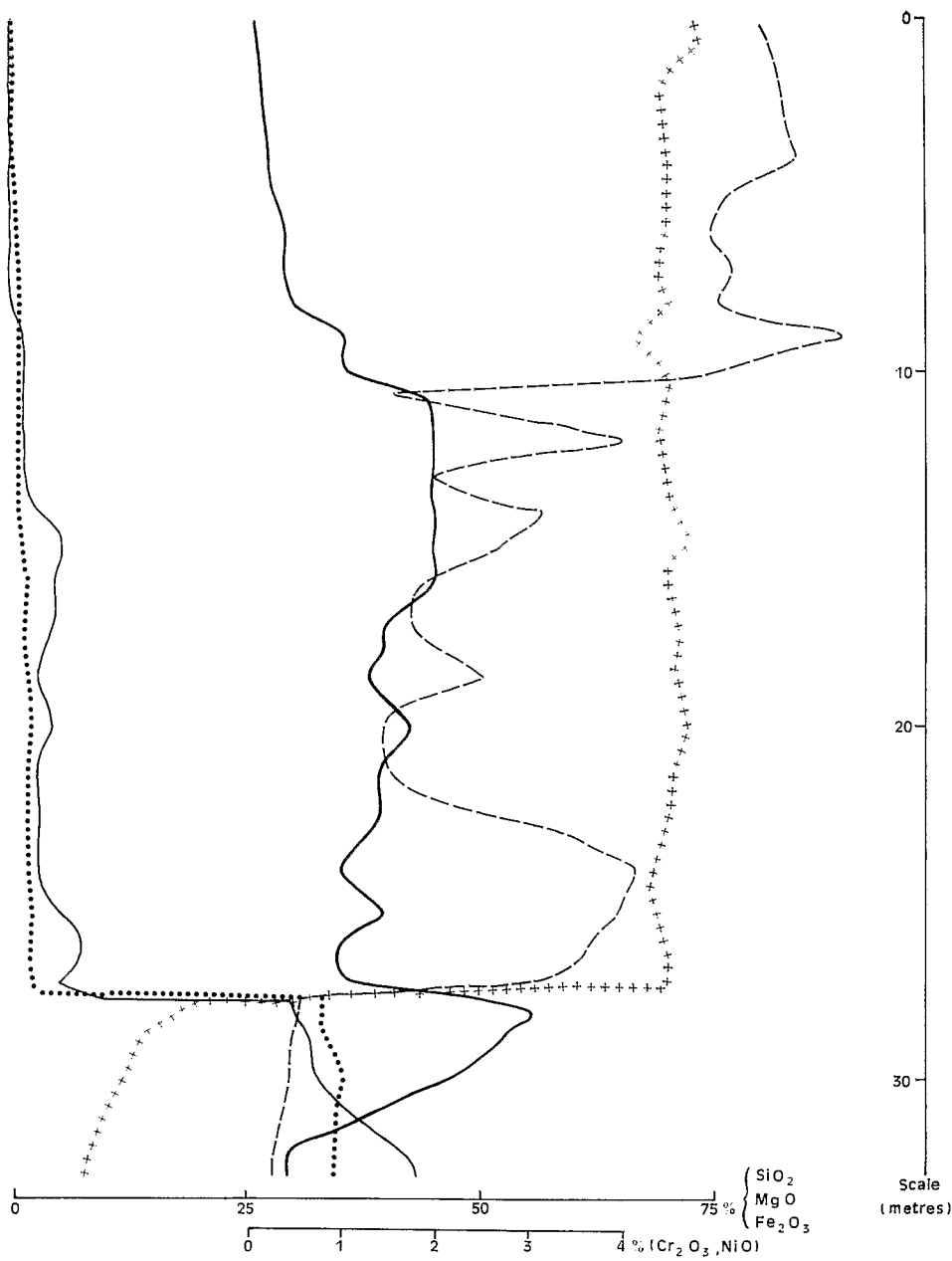


Fig. 3. Grain-size distribution through the profile (plateau).

- a $\theta > 2 \text{ mm}$
- b $2 \text{ mm} > \theta > 0.2 \text{ mm}$
- c $200 \mu > \theta > 50 \mu$
- d $50 \mu > \theta$
- e H_2O

- 1 Ironcrust
- 2 Granular laterite
- 3 Crushed saprolite
- 4 Fine-grained saprolite
- 5 Coarse-grained saprolite
- 8 Fresh peridotite



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Fig. 4. Geochemical behaviour of the elements during weathering.

SiO ₂	Fe ₂ O ₃	++++
MgO	————	NiO	———
		Cr ₂ O ₃	---

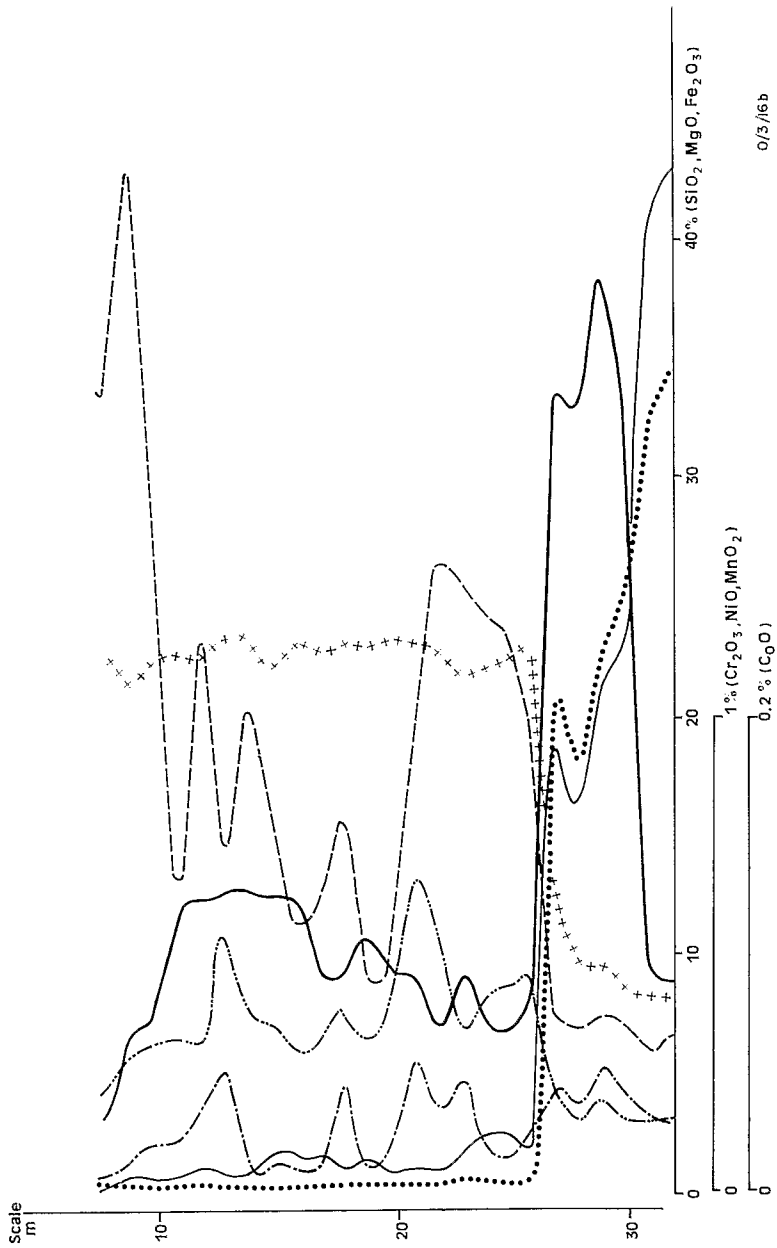


Fig. 5. Balance sheet of the weathering (isovolumetric computation).

SiO ₂	NiO	-----
MgO	————	Cr ₂ O ₃	- - - -
Fe ₂ O ₃	+++++	MnO ₂	· · · · ·
		CoO	- · - · -

TABLE 1. ANALYTICAL DATA COMPARING WEATHERING LAYERS, IN WELL-DRAINED AREAS (AVERAGE AMOUNTS, IN PERCENT)

No.	Thick- ness	Lost Ignition	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Cr ₂ O ₃	MnO ₂	NiO	CoO	TiO ₂	S—
1	0.5 m	14.8	0.10	73.2	4.42	0	0	5.54	0.52	0.17	0.010	0.26	—
2	6.5 m	13.4	1.49	69.2	8.49	0	0.07	5.39	0.50	0.31	0.022	0.15	—
3	20 m	13.4	1.65	70.5	3.08	0.06	4.15	2.69	1.23	1.54	0.080	0.17	0.35
4	4 m	14.3	24.16	36.19	0.71	0.22	19.53	0.39	0.54	3.11	0.095	0.28	—
5	4 m	12.7	37.04	12.71	0.45	0.19	33.78	0.55	0.20	2.54	0.072	Tr.	—
6	0.5 m	14.5	36.47	11.08	0.23	0.08	31.92	0.21	0.21	2.41	0.067	0.08	—
7	0.5 m	13.7	35.53	12.48	0.64	0.11	33.68	0.55	0.23	2.36	0.084	Tr.	—
8	below 28.5 m	11.3	34.9	8.34	0.27	0.16	42.63	0.31	0.14	0.44	0.030	0.07	0.013

1. Iron crust; 2. gravelly laterite; 3. fine-grained saprolite; 4,5,6,7. coarse-grained saprolite (4. Top, fraction <50 μ ; 5. Top, fraction >2 mm; 6. bottom, fraction <50 μ ; 7. bottom, fraction >2 mm); 8. fresh peridotite.

Systematic chemical analysis of the spring waters shows (Trescases, 1969b) that this ferrallitic weathering occurs in the wet season, whereas the formation of talc and antigorite prevails during the dry season. These secondary silicates trap the nickel released by weathering and that leached from higher horizons. The chromite crystals, which contain aluminium and a small proportion of iron and magnesium, are the most resistant minerals.

Fine-grained saprolite. This is a homogeneous layer, brownish-red to brownish-yellow in colour; 80-90 percent is of grain size less than 50 μ . The coarse fraction (100 to 500 μ) consists of:

- residual chromite crystals, partly weathered into gibbsite and hematite;
- some pyroxene crystals, little weathered;
- a little secondary quartz, inherited from the coarse-grained saprolite, in which silica has been precipitated;
- asbolane concretions (manganese and cobalt oxides, with some nickel).

The fine-grained fraction is chiefly ferruginous (goethite and hematite) and contains most of the nickel (hydroxide) of this layer.

Almost the whole of the silica and magnesia, which had remained in the coarse-grained saprolite level, has been removed; only the residual elements (iron, chromium, aluminium, manganese, titanium, cobalt, nickel) remain. These elements are relatively concentrated (lateritic nickel and cobalt ores) by the removal of the soluble elements. However, some nickel is rendered unstable and is leached towards the lower part of the profile, and concentrated at the interface between the weathered zone and the fresh rock below. This nickel is combined with silica and magnesia, as antigorite, talc, chlorite, or mixed gels (garnieritic nickel ore).

Laterite and iron crust. The downward movement in situ of the fine-grained saprolite, and the formation of iron hydroxide concretions, results in the formation of an uppermost soil layer (ironshot soil or laterite). This red, granular, lateritic horizon is duricrusted by iron crust-forming processes, when the morphological environment is favourable.

Slopes

Most slopes are very steep, as a consequence of the recent tectonic rejuvenation of the topography. Degradation of the plateau gives way to a colluvial process which provides the slopes with ferruginous material similar to the upper levels of the plateau weathering profiles. The type of weathering on slopes looks very much like that of the bottom of the plateau profiles (antigorite, talc, chlorite), but erosion does not allow weathering to proceed sufficiently far to form ferruginous layers or economic concentrations of nickel.

Poorly drained areas

Piedmont

The material removed from the well drained areas, transported by suspension in the rivers or by colluvial processes on the slopes, accumulates at the base of the hills, as gently sloping piedmont deposits.

Beneath a ferruginous colluvial layer, a zone of in-situ weathering is usually observed (fine and coarse-grained saprolite), but the profile rarely exceeds 15 m in depth.

Table 2 shows the chemical variation in a typical profile. The sampling was done in a bore hole, in the Yate River basin (southern part of New Caledonia), near the 'Rivière Blanche' swamps.

TABLE 2. ANALYTICAL DATA COMPARING WEATHERING LAYERS IN POORLY DRAINED AREAS (FOOTHILLS) (AVERAGE AMOUNTS IN PERCENT)

No.	Thick- ness	Bulk density	Lost ig- niton	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Cr ₂ O ₃	MnO ₂	NiO	CoO	TiO ₂
1	2.5 m	—	12.6	1.87	68.69	9.44	0	0.94	3.64	0.91	0.41	0.08	0.30
2	7.5 m	0.75	11.4	5.34	67.14	6.92	0	1.22	5.18	1.29	1.31	0.16	0.23
3	1 m below	0.82	10.2	31.48	28.01	1.21	0	25.59	1.04	0.34	1.71	0.06	0.08
4	11 m	2.71	12.4	37.30	7.86	0.35	0.06	40.79	0.09	0.15	0.24	Tr.	0.04

1. gravelly laterite (colluvium); 2. fine-grained saprolite; 3. coarse-grained saprolite; 4. fresh peridotite.

The comparison of this profile with the Kouaoua profile (well drained ironstone-capped plateau) suggests that in a piedmont area:

- no ironcrusting process took place;
- the upper colluvial level is a little richer in silica than the upper level of the high areas (because antigorite and talc, not present in this layer on the plateaux, are contained in piedmont areas, as inherited minerals from the slope weathering profiles);
- the amount of silica in the fine-grained saprolite layer is clearly higher than in its homologue on the plateaux, but the increase in magnesia content is less: this material consists largely of nontronite resulting from the combination of the dissolved silica migrating from high areas with iron hydroxides from the laterites;

—the coarse-grained nickeliferous saprolite horizon resembles the corresponding layer on the plateaux, but contains also a little nickeliferous nontronite.

Confined environments

These environments are an extension of the piedmont deposits described above, and constitute a local base level. Such environments occur in the swampy lowlands of the peneplain—closed basins filled by ferruginous detrital materials (dolines and poljes)—and on the coastal alluvial plain which separates, on the west coast, the peridotites from the seashore. It is therefore a sedimentary (alluvial) environment, rather than a weathering one, but the coarsest fragments (cobbles, pebbles, gravels) are weathered according to the peculiar geochemical characteristics of this environment. The thickness of sediment can be as much as 70 m.

TABLE 3. ANALYTICAL DATA COMPARING SEDIMENTARY LAYERS IN POORLY DRAINED AREAS (SWAMPY LOWLANDS) (AVERAGE AMOUNTS IN PERCENT)

No.	Thickness	Lost Ignition	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	MgO	MnO ₂	Cr ₂ O ₃	NiO	CoO	TiO ₂	Organic C
1	6.5 m	13.15	2.34	64.72	11.69	0.69	0.59	3.40	0.73	0.04	0.33	0.12
2	1.5 m	12.25	13.40	50.04	13.66	1.46	0.36	5.87	0.65	0.41	0.30	0.21
3	5 m	10.01	16.91	43.18	14.90	3.10	0.25	6.18	0.94	0.07	0.31	0.28
4	1 m	13.59	13.38	55.85	8.11	2.08	0.33	2.44	0.98	0.04	0.23	1.47
5	3 m	11.02	15.35	50.03	10.48	3.24	0.25	3.39	0.85	0.04	0.26	1.17
6	1.5 m	10.73	16.82	49.14	13.72	2.64	0.38	3.36	0.66	0.04	0.27	0.80
7	1 m	11.15	23.89	34.08	17.11	5.83	0.21	4.30	0.55	0.02	0.33	0.64
8	0.5 m	49.47	13.61	10.49	9.47	10.25	0.16	0.88	2.60	0.13	0.15	11.80
9	5 m	10.38	25.35	32.64	19.22	4.24	0.30	2.62	0.55	0.02	0.40	—
10	1 m	6.50	19.59	36.31	15.39	5.32	0.32	9.67	0.70	0.03	0.48	0.25
11	1 m	8.25	27.80	35.76	12.10	7.84	0.30	4.09	0.70	0.01	0.30	0.10
12	1 m	6.49	28.20	29.05	15.42	9.12	0.35	9.69	1.46	0.03	0.48	0.15
13	2 m	8.83	35.38	22.35	7.96	20.66	0.42	1.94	0.55	—	0.11	—

- | | |
|----------------------------------|---|
| 1. Gravelly laterite (colluvium) | 8. Peat |
| 2. Fine-grained red deposit | 9. Iron-crust |
| 3. Fine-grained grey deposit | 10. Fine-grained grey deposit |
| 4. Iron-crust | 11. Iron-crust |
| 5. Fine-grained grey deposit | 12. Fine-grained grey deposit |
| 6. Iron-crust | 13. Weathered peridotite pebbles (fine-grained saprolite) |
| 7. Fine-grained grey deposit | |

A typical profile was sampled in a bore hole, very near the piedmont profile previously described, in the 'Rivière Blanche' swamps. Table 3 shows the chemical characteristics of this unit:

- from 0 to 6 m, a ferruginous granular layer, with a little antigorite of grain size lower than 50 μ , like the colluvial uppermost layer in piedmont areas.
- from 6 to 8 m, a red, ferruginous, fine-grained deposit, with antigorite and nontronite.
- below 8 m, the environment is reducing; the general colour is blue to green. The medium-grained layers (antigorite and iron hydroxide concretions)

alternate with fine-grained layers (talc, antigorite, slightly nickeliferous nontronite). In places very coarse-grained layers are observed, consisting of cobbles and pebbles completely altered to nontronite and antigorite (Gonard & Trescases, 1970); also peat deposits (50% loss on ignition) with nickeliferous nontronite (5 to 6% NiO) interbedded with the clastic sediments; and several duricrusted layers resulting from the oxidation of iron during fluctuations of groundwater level in the course of sedimentation, with the detrital fragments cemented together by precipitated ferric iron (Fe^{+++}).

With the exception of the peat layers, unfortunately thin (less than 1m) and discontinuous, the amount of nickel in these deposits is almost the same as the amount in the weathering layers of the fine-grained saprolite type. But this amount increases with the nontronite content and, in some cases, these deposits can become nickel ores.

CONCLUSIONS

In New Caledonia the effects of laterite weathering are distributed throughout the terrain, affecting, according to the laws of surface geochemistry, the constituent elements of the ultramafic rocks.

Each element is concentrated in the theoretical topographic sequence, from the top of the ridges to the seashore (and eventually in the ocean), according to the scale of the relative mobility of these elements (Tardy, 1969; Trescases, 1969b).

Iron, chromium, titanium, and aluminium are the least mobile elements, and are found in the upper part of the weathering profiles, on the highest and oldest surfaces, particularly in the ironstone capping, as hydroxide concentrations (goethite, a little gibbsite) or as residual mineral (chromite, magnetite). When these residual layers are destroyed by erosion, these elements migrate nevertheless toward lower surfaces, but by mechanical processes: by colluvial process on the slopes, or by suspension in the river waters.

Cobalt and manganese are concentrated, as hydroxide concretions, in the middle part of the weathering profiles of these highest surfaces, which are poorly protected against erosion and mechanical transportation. The behaviour of nickel is similar to that of cobalt and manganese, but its relative mobility is a little higher in the weathering zone. It is partly leached out of the hydroxide concretions, where it is first concentrated with Co and Mn, and largely migrates to the bottom part of the profiles: it is a guest element of the newly formed magnesian silicates (talc, antigorite, swelling chlorites) of the high surfaces, and of the newly formed feruginous silicates (nontronites) of the low surfaces, where it is associated with concentrations of organic material (peat).

Silica is slightly less susceptible to leaching than magnesia. Most of the silica released by weathering is transported by underground and river waters (dissolved silica), but it is combined, mostly with detrital iron, as nontronite, in poorly drained areas, that is to say in the low areas underlain by peridotite, and chiefly near the seashore, in the flood plain and mangroves. A part of the silica remains in the weathering zone, by precipitation in the joints and fractures of the rocks, as silica

gel, chalcedony, quartz, or, in combination with magnesia, as talc, chlorite, or antigorite. Nickel is a guest element in all these minerals.

With the exception of the amount taken up by the secondary silicates, the main part of the magnesium migrates by underground and river waters. Under certain conditions, a part can precipitate near the seashore, as giobertite.

This new distribution through the terrain of the elements of ultramafic rocks, which can result in economic concentrations, particularly of nickel, corresponds to an ion chromatography through the topographic sequence of soils and sediments.

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ELEMENTS OF ULTRAMAFIC ROCKS IN NEW CALEDONIA**

by

J. J. TRESCASES

*Issued under the authority of the Hon. R. F. X. Connor, M.P.,
Minister for Minerals and Energy*

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