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Structural and Petrogenetic Aspects of the Baruta Area in the Venezuelan Coast Range

By **Hans P. Laubscher**

With 9 Figures

Introduction

Until a short time ago the geology of the Venezuelan Coast Range was little known except for its general features (Aguerrevere & Zuloaga, 1937). It has been only in the last few years that detailed information has been obtained through the mapping and petrographic investigations of Dengo and Smith (1953) who covered the quadrangle sheets of Caracas and Los Teques. For the general geology of the area of Caracas the reader is referred to the quoted treatises. We wish to mention here only those aspects bearing on the thesis of this paper.

The rocks of the Baruta area are dynamometamorphic; most of them show the lowest-grade metamorphism of the greenschist facies. Several "formations" have been distinguished but in the present paper we shall deal only with the Las Brisas "formation". It consists mainly of quartz-mica schists and soft sericitic to graphitic schists with intercalated lenses, blocks, and bands of dark limestone and dolomite. Associated with these carbonate bodies are usually light-colored beds of calcareous microcline gneiss. A higher "formation", not discussed in this paper, contains large masses of calcareous and micaceous schists which are similar to the calcareous series of the *Bündnerschiefer* in the Alps. A great similarity of this part of the Coast Range with the Penninic nappes of the Alps is also borne out by the presence of serpentines, amphibolites, glaucophane schists, and eclogitic rocks. Except for some of the beds of microcline gneiss all of these rocks are intensely kneaded by tectonic processes.

The data on which this paper is based were obtained by the writer on weekend trips during several years of residence in Caracas. In some instances he has been able to add new observations to those already reported by Dengo and Smith, whereas in others he presents an alternative interpretation. The writer wishes particularly to emphasize that the tectonic and petrogenetic processes of this small segment of the Coast Range are of more than local significance since he was able to ascertain on field trips to the Alps in the summer of 1954 with Professor Bearth of Basel, that similar processes are also characteristic of the Pennine system.

The present paper deals mainly with observations from quarries south of Caracas in the vicinity of Baruta (Figure 1). These quarries, in which dolomites and microcline gneisses are excavated, permit detailed observations which are not possible elsewhere because of the deep weathering. Here it becomes manifest that the carbonate intercalations are tectonic forms such as *boudins*, rotated blocks, and tectonic lenses. They are enveloped by a zone of mechanically disintegrated rocks which sometimes resemble true sedimentary conglomerates. The dolomites grade through the various transitional stages of mechanical destruction, chemical mobilization, and recrystallization into the calcareous microcline gneisses. Wherever detailed studies are possible these gneisses are recognized as rocks newly formed during metamorphism. Apparently they represent a metamorphosed sequence of clastic sediments, but in reality they are secondary, essentially metasomatic rocks without

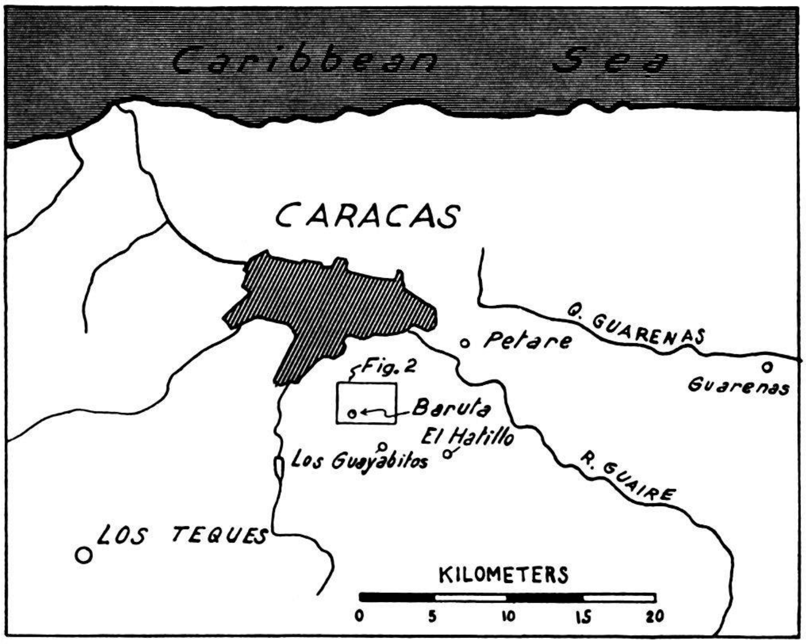

Fig. 1. Map of the Caracas region, Venezuela, showing the location of the Baruta area represented on Fig. 2.

a simple stratigraphic equivalent. Their development was preceded by mechanical disintegration and mechanical and chemical mixing of different stratigraphic elements. There are suggestive similarities with the phenomena of granitization, such as the occurrence of relics in the microcline gneiss, some with sharp boundaries, others with diffuse transitions into the matrix. Fluidal structures and *schlieren* may be found, but they were formed at low temperatures and certainly without participation of a molten phase.

Solid flow with *boudinage*, rotation, mechanical and chemical mixing appear to be large-scale tectonical processes; accordingly, the regional tectonics get a new look. The "Baruta anticline" (AGUERREVERE and ZULOAGA, 1937; DENGO, 1953; SMITH, 1953) becomes a slight undulation which is superimposed on an intense and complex basic structure, and it may be preferable to use the term "zone" instead of "anticline". The "formations" are lithologic complexes, not stratigraphic sequences.

In connection with this paper it is our pleasant duty to express grateful acknowledgement to Professor P. BEARTH of Basel. He discussed our problems in letters and orally. He had thin-sections made for us and examined and commented on them. And above all, he encouraged us to

write this paper. We are also indebted to Messrs. N. E. WEISBORD and M. C. PARSONS of Socony Mobil Oil Co. de Venezuela for their valuable criticism.

In the following sections the phenomena described above in general terms will be discussed and represented in somewhat more detail, especially for three of the examined quarries.

1. Quarry 500 meters south of Baruta, east side of road

(Figs. 2, 3)

South of Baruta one of the zones of dolomitic blocks crosses the little valley which heads towards Los Guayabitos. This zone is quarried on both sides of the valley, and Figure 3 is a view of the eastern quarry as seen from the west in April, 1952.

A jointed and somewhat fractured but otherwise massive block of dark gray dolomite (*R* on Figure 3) occupies the central and upper part of the quarry. It has a diameter of 10 to 15 meters. A thick zone of disintegrated and partly pulverized rocks flow around this block and occupy the remainder of the quarry. These tectonic clastics consist of fragments of all orders of magnitude. They are arranged in layers which may simulate original sedimentary beds. However, all stages of tectonic disintegration are present, and there is no doubt about the tectonic origin of these layered rocks. These layers envelop the block and adapt themselves to its shape

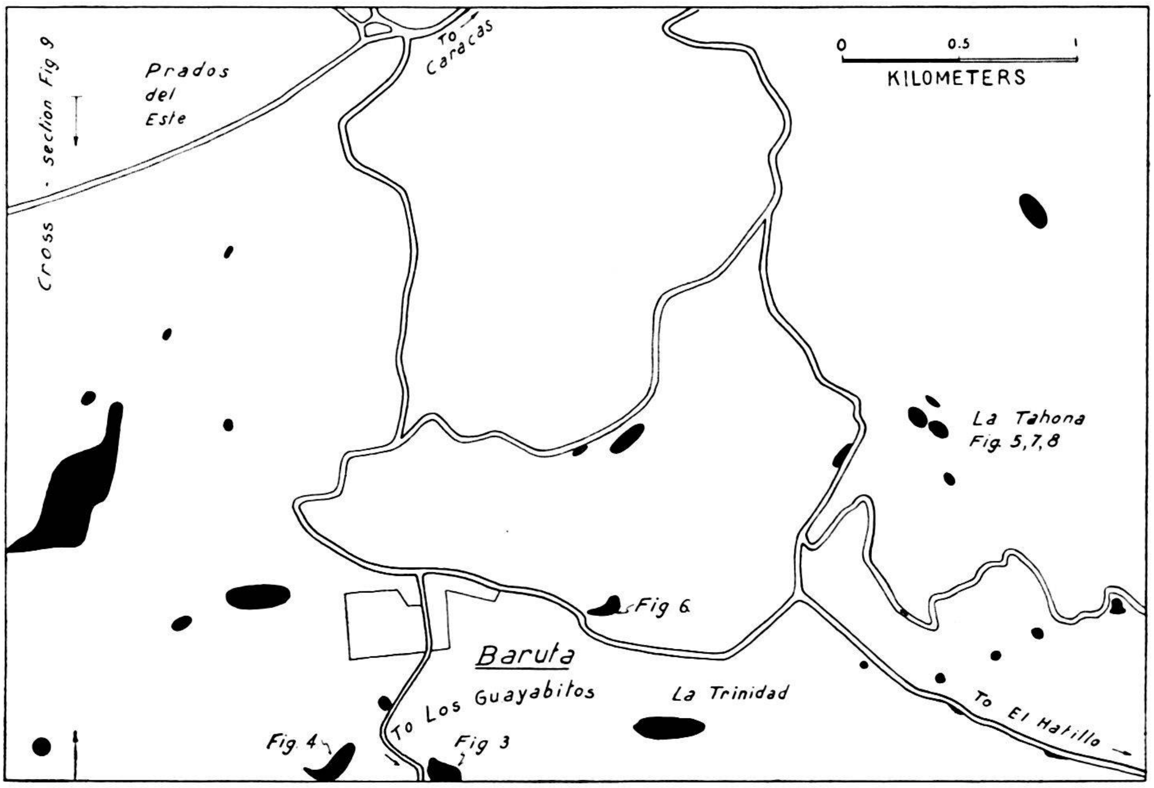

Fig. 2. Map of the Baruta area south of Caracas showing the outcrops of dark-colored dolomites and limestones. Only the main roads are drawn. New housing developments with a large number of roads are being constructed for rapidly expanding Caracas. New roadcuts will no doubt expose a number of carbonate bodies previously hidden. This map must therefore be considered as preliminary and incomplete.

and cause thus the impression that they flow around it. The flowage layers from opposite sides of the block meet again at the points marked *B* and *B′* on Figure 3.

Similar flowage on a smaller scale is known from the phenomenon of *boudinage*. It usually occurs where incompetent plastic beds flow on both sides of a competent

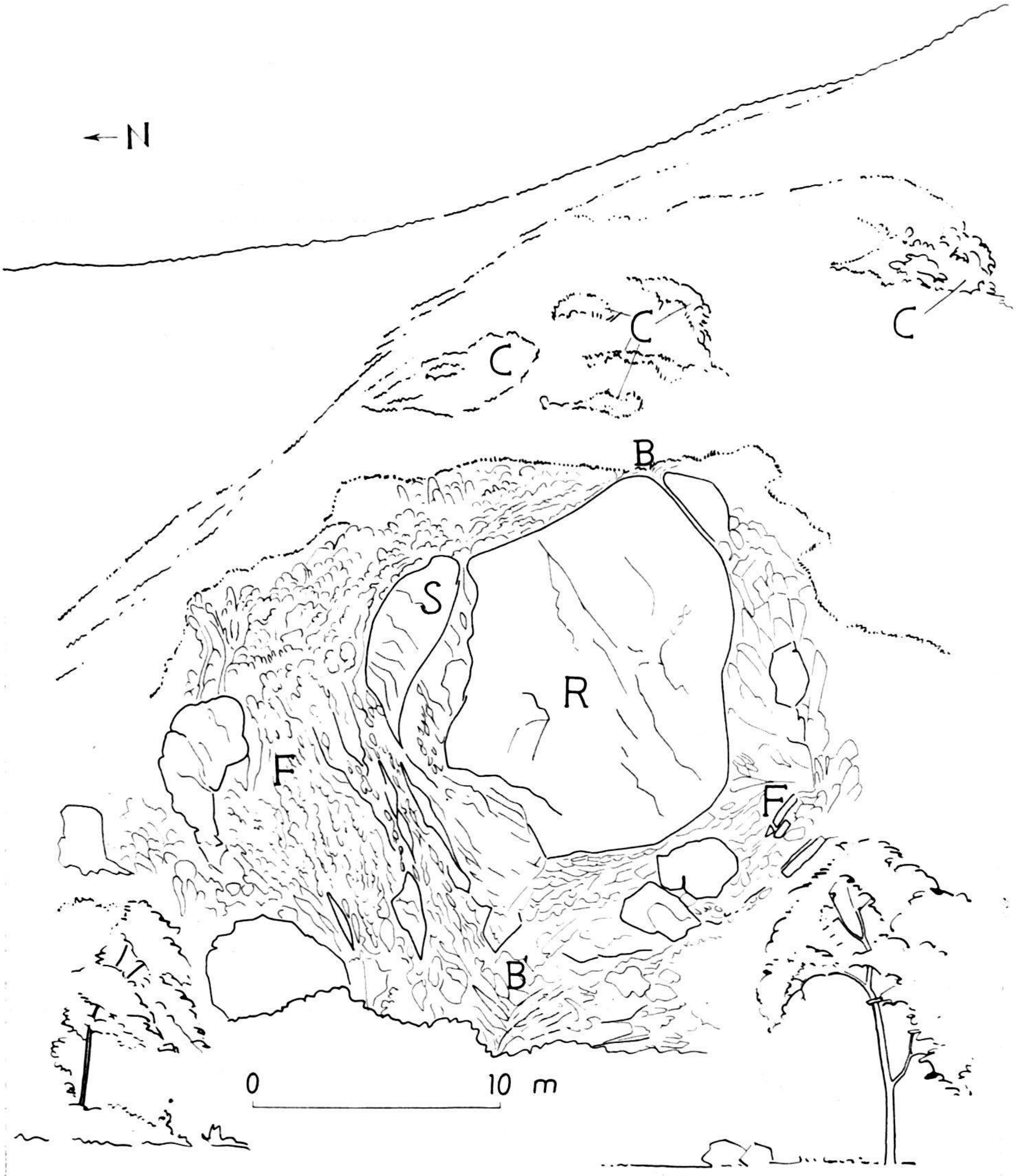

Fig. 3. The quarry 500 meters south of Baruta, east of the road to Los Guayabitos, as seen from the west in April 1952.

R = large massive relic of dark dolomite,
F = flowage zone with smaller massive relics,
S = splinter sheared off from main block,
B and *B′* = points where flow layers from opposite sides of the main block meet,
C = carbonate blocks above the quarry.

layer and dissect it in a series of sausage-like lenses (see RAMBERG, 1952, p. 124). In our case, however, the flowing rock had originally been competent; flowage was preceded and accompanied by mechanical disintegration, and the pulverized masses then flowed around the massive relic, shearing other fragments from it and thus gradually reducing it.

This flowing around massive cores is not restricted to the large block. It recurs in all orders of magnitude down to microscopic dimensions. Flowage zones of different orders may thus be distinguished:

(1) the entire zone of clastics which flow around the large block;
(2) flowage zones of smaller components which surround the larger components of the first zone, etc.

Besides the different orders of flowage zones there are different generations of tectonic clastics. For in the flowage zone there is chemical mobilization and recrystallization as well as mechanical disintegration. During these chemical processes the originally dark carbonate looses its color, and, in addition, fresh material in the form of quartz and feldspar is supplied. By this recrystallization process a competent calcareous microcline gneiss develops in the formerly incompetent flowage zone. We shall deal with this phenomenon in some detail in section 4. At present we limit our interest to the fact that these newly formed competent rocks are frequently subjected to renewed mechanical destruction, and thus constitute tectonic clastics of the second generation.

The microcline gneisses are prominent in the northern half of the quarry. In the southern half the carbonate material usually is disintegrated and recrystallized with less silicate material. The dolomite is broken up to form lenses, or plates, or it is compressed and rolled out to form thin sheets. Essentially, however, the same processes of flowage have taken place as in the northern half.

At point *B* on Figure 3 the flowage zones from opposite sides of the large block meet, as already mentioned. Only a few feet above this point, however, they separate again, bending back to the north and south as if another massive block higher up were to be enveloped. And, in fact, some dolomite boulders pierce through the grassy slope above the quarry (*C* in Figure 3). There are also smaller massive blocks of a few meters diameter at the foot of the northern end of the quarry and they, too, are surrounded by tectonic clastics.

To summarize, it may be said that this belt of dolomitic rocks corresponds to a zone of pinch-and-swell structure, that is, of large-scale *boudinage*. The dolomite had originally been a competent rock but was partially subjected to flowage by successive mechanical disintegration and abrasion. The clastic part then flowed around the massive relics. New rocks, especially microcline gneisses, formed in this zone of flowage because of chemical mobilization and recrystallization.

2. Quarry 500 meters south of Baruta, west side of road
(Figs. 2, 4)

A similar situation is observed on the opposite, western side of the valley. It corresponds to the western continuation of the zone of dolomite *boudins* we have just discussed. Figure 4 shows the quarry, again as it was seen in spring, 1952. Conditions have changed very slightly in the meantime.

The quarry is over 100 meters long. Its southern part consists of a large massive relic some 20 to 30 meters in diameter, whereas the northern part, representing about two thirds of the quarry, is composed mainly of tectonic clastics and recrystallized rocks with smaller massive relics.

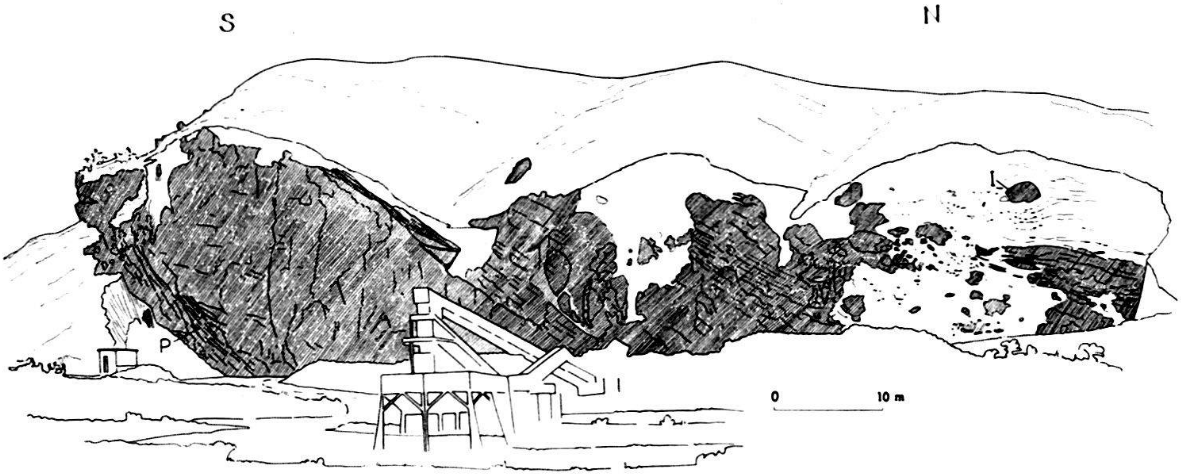

Fig. 4. The quarry 500 meters south of Baruta, west of the road to Los Guayabitos, as seen from the east in April 1952.

The *crosshatched areas* represent massive dolomite and tectonic clastics consisting predominantly of dark carbonate.

I = isolated block of dolomite embedded in schists, *P* = zone of platy parting.

At the southern foot of the large massive block a north dipping zone of shearing and platy parting (*P* in Figure 4) separates an agglomeration of small blocks from the main mass. This agglomerate is bounded on the south by micaceous schists dipping about 50° north. Some blocks are also embedded in these schists which are possibly the mylonitic equivalent of microcline gneisses. A few bands of such gneisses crop out along the road some meters farther south.

The northern end of the massive block is roofed by beds of microcline gneiss dipping about 30° north. They contain numerous small dolomitic relics and grade into microcline bearing recrystallized tectonic clastics which make up the central part of the quarry.

In the northernmost part of the quarry the dolomite disintegrates in a mass of more or less isolated blocks and chips. A striking occurrence is the block labeled I on Figure 4. Here the dolomite is completely isolated as it lies within the mica schists of the roof of the quarry. Such comparatively small isolated blocks are also found elsewhere in the area, surrounded by mica schists. Figure 4 suggests that such blocks were sheared off and dragged away by the schists flowing around the dolomite zones.

3. The "La Tahona" quarry

(Figs. 2, 5)

This quarry is located at the foot of a hill which consists of microcline gneiss with embedded relics of dark carbonate. The zone of microcline gneiss is over 100 meters thick. It strikes about west and dips over 40° north, but there are many local irregularities in the flowage zones around the dolomite blocks. The dolomitic relics occur mainly in two major complexes of which the lower one has been excavated in the quarry. Its extremely complicated structure is suggested on Figure 5. The dolomitic relics are of all orders of magnitude. They are individually enveloped by partly recrystallized but largely mylonitic schist-like tectonic clastics. Several of the competent blocks are of the second and higher generations.

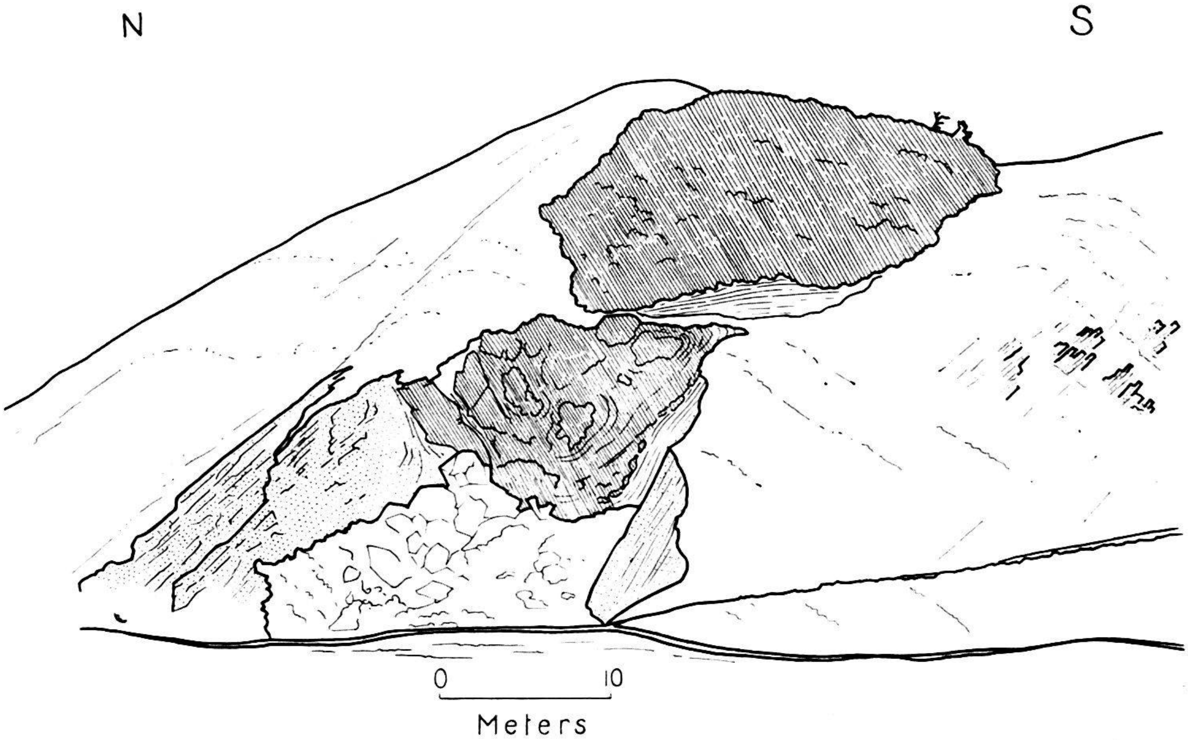

Fig. 5. The La Tahona quarry as seen from the west in April 1952.
The *crosshatched areas* represent zones where dark dolomites predominate.
The *dotted areas* represent zones where light-colored microcline gneisses predominate.

Especially significant are the microcline gneisses north of this dolomitic complex. They contain an abundance of comparatively small relics of dark dolomite in the various stages of disintegration and recrystallization. The dark relics are merging diffusely with the light-colored dolomitic gneiss, or they have been almost entirely bleached. A more detailed description of these transitions will follow in the next section. In addition to these dolomite relics the gneiss contains linear sericitic inclusions.

Above the quarry, separated from it by a few meters of whitish, micaceous, mylonitic rock, there is the second complex of dark dolomite relics. However, this has not been quarried and the detailed structure cannot be unravelled because of the deep weathering.

It is interesting to observe the foliation of the microcline gneisses south of the quarry. The gneisses surround the two complexes of dark dolomite and flow into the gap between them. They become mylonitic in the vicinity of the dolomite and especially in the gap between them. These features are typical of tectonic pinch-and-swell structures, that is of *boudinage*.

On the whole these outcrops again reveal a north dipping zone of mechanically disintegrated dark dolomite, subjected to flowage and *boudinage*, and grading into light-colored dolomitic microcline gneisses. Again, the gneisses have formed secondarily by crystallization in the zone of detrition and flowage around the relics of dark dolomite.

4. The mechanical disintegration of the dolomite and the formation of microcline gneisses

(Figs. 6, 7, 8)

In the preceding chapters the structure of the zone of tectonic clastics has been mentioned, and the complexity brought about by the interaction of mechanical destruction and chemical recrystallization has been emphasized. We should like now to elaborate on these in some detail.

Regional considerations suggest that the dolomite had originally been deposited as a continuous limestone bed. The initial stages of tectonic deformation and mechanical disintegration were obliterated by the intensity of the later movements. One could imagine that the limestone bed was first dissected by a system of faults and surfaces of shearing, or by rupture following intense folding; or that the competent bed was first subjected to *boudinage* by differential flowage of shales on both sides; or, it is even conceivable that the limestone bed formed a coastal cliff at an early stage of orogenic movements, and that individual slump masses were embedded in younger sediments after the fashion of *wildflysch* sedimentation.

Fortunately the further stages of disintegration and recrystallization can still be seen. First the competent dolomite is fractured as a brittle rock. Open cracks are formed which are filled with white carbonate and quartz. Simultaneously surfaces of shearing and slippage develop; the rock begins to flow and *boudins* and lenses are formed. The filled cracks are deformed concomitantly with the rest of the rock and become an oriented part of the flowage system in the form of subparallel light-colored stripes. By the continuous deformation and recrystallization their borders become diffuse. Flowage is not restricted to the readily visible system of surfaces of slip, but usually affects also the interior of the smaller lenses and *boudins*. Most of these are not relics of the original massive dolomite. Closer inspection reveals internal surfaces of gliding which have been more or less obliterated by recrystallization. Most of these boudins and lenses are merely bodies where recrystallization prevails over disintegration, that is, they are bodies of relative, not absolute, resistance to flowage. These local conditions vary strikingly with time. At successive stages the local ratio of recrystallization to disintegration is often reversed; the active and passive roles are exchanged. An original *boudin* dissolves to become part of the flowage zone, while a former part of the flowage zone solidifies to form a *boudin*. A *boudin* consisting of heterogeneous recrystallized tectonic clastics is now enveloped in its turn by a flowage zone of dolomite particles.

This entire heterogeneous flowage zone in which relics of dark carbonate are associated with depigmented and recrystallized rocks (the latter developing from the former), grades into a more and more homogeneous light-gray to white carbonate-quartz-microcline gneiss. Figures 6, 7, and 8 demonstrate this transition.

Figure 6 represents a block from the outcrop north of the Baruta–La Trinidad road (Figure 2). It shows a zone of movement in which relics of various magnitude of the dark dolomite are embedded. The carbonate is coarsely recrystallized throughout. The relics occur mostly in the form of *boudins* and lenses with drawn-out endings, but sometimes, they are rounded instead of attenuated (*R* on Figure 6). Such rounded bodies may resemble true sedimentary pebbles, especially when consisting of heterogeneous recrystallized rock. Three-dimensionally, most of these relics are flat lenses compressed between the planes of schistosity. Projected on this plane they are usually isometrical or only slightly elongated. Sometimes, however, they are not compressed but isometrical in all three dimensions.

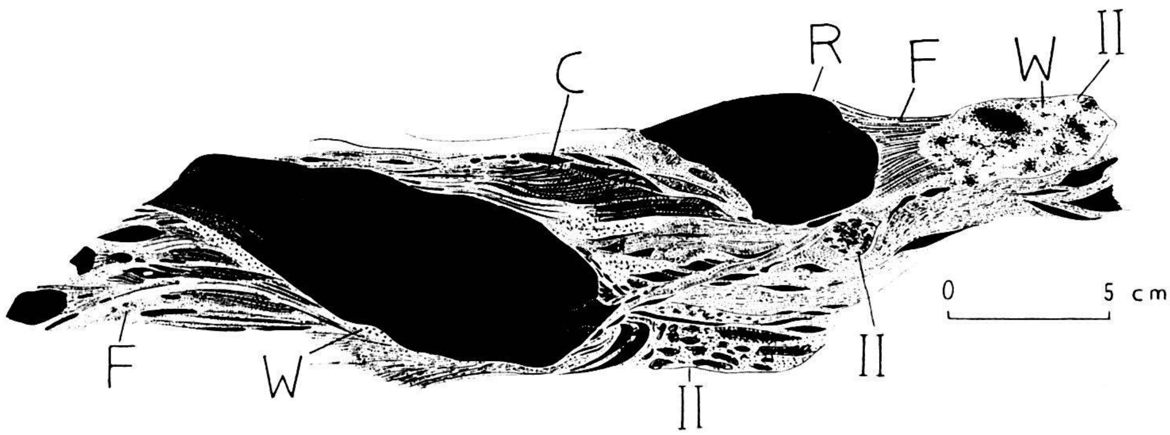

Fig. 6. Detail from zone of tectonic clastics (flowage zone) in outcrop 500 meters east of Baruta (see Fig. 2).

C = pseudo-crossbedding,
F = flow layers consisting mainly of finely ground carbonate with sericitic coating,
W = recrystallized white carbonate and quartz,
R = rounded pseudo-pebble,
II = tectonic clastics of the second generation.

The structure of the flowage zone is extremely complex. We have not been able to represent it except for a suggestion of the most prominent features. Thin lenses, laminae, and grains of dolomite are separated from each other by sericitic coatings which are often very thin, but may sometimes reach a thickness of several millimeters. Most of these coatings apparently developed from intensely ground and then decarbonated zones. They often grade into successively coarses and darker carbonate, and in this way they may merge with the *boudins* without an exactly defined boundary. In some places they may have developed from original shaly stringers partaking in the general flow. Closely spaced younger shearing and gliding surfaces often intersect obliquely the older ones. They demonstrate the variability of flowage conditions with time even in the slightest detail. Imagine the difficult problem of a fabric analyst if he happens to be confronted with a specimen still containing relics from all these different phases! The system of flow lines often resembles sedimentary cross-bedding (C on Figure 6). Such pseudo crossbedding is frequent also on a larger scale. Recrystallization of unpigmented quartz and carbonate is common throughout the flow zone. However, it should be inferred from the complexity of the process of flow that the present location of these unpigmented products of recrystallization does not, generally, correspond to the place where they originated. Sometimes recrystallization in the pressure shadow of *boudins* may still be observed, a process often described in literature. Since the whole flowage zone is composed of lenses of all orders of magnitude, there was certainly a large system of relative pressure shadows–varying with time–which favored recrystallization. Other places of recrystallization are open cracks which have been mentioned previously. Continuous mixing of dark and light components by flowage results in a speckled aspect of many parts of the zone, and such parts may solidify by recrystallization and subsequently act as resistent *boudins* and lenses of the second generation. The three bodies labeled II on Figure 6 are of this nature.

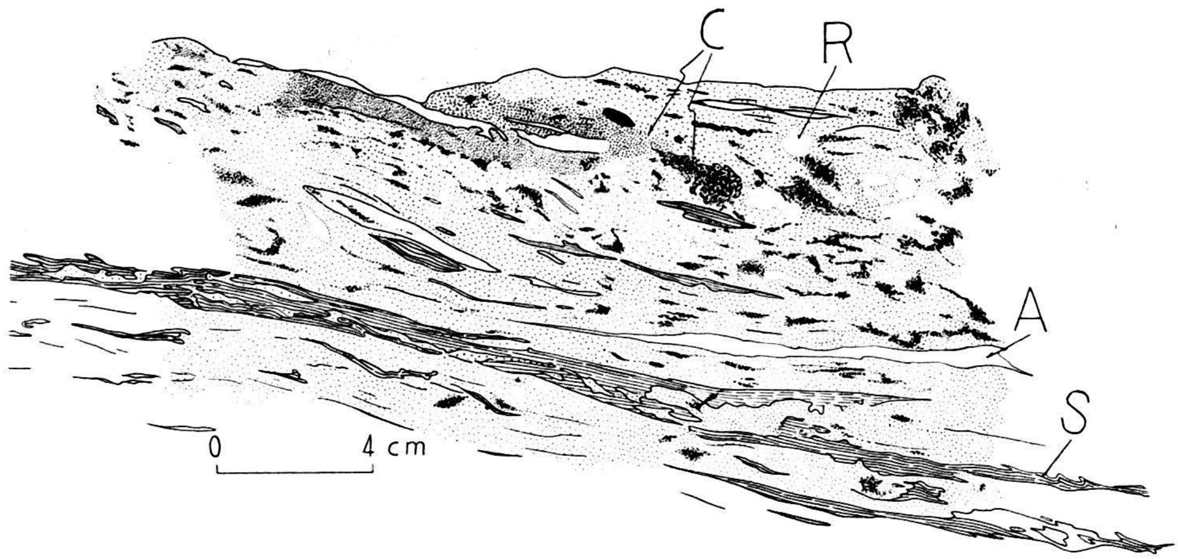

Fig. 7. Detail from the transition zone between tectonic clastics and recrystallized microcline gneisses, north wall of La Tahona quarry.

C = diffuse relics of dark carbonate,
S = sericitic stringers,
A = finely grained aggregate consisting mainly of white carbonate, quartz, and mica,
R = recrystallized white carbonate and quartz.

Figure 7, from the northern zone of the La Tahona quarry, shows a more advanced stage of the development of microcline gneiss. The *boudins*, lenses, and bands of the dark dolomite may still be recognized. However, they are usually without a sharp boundary as they merge with their surroundings. Often this process has advanced to the point where they appear as mere blotches and spots of a somewhat darker shade in the light-gray matrix. The rock is still more or less schistose, yet without the pronounced flowage zones seen on Figure 6. Coarse recrystallization affects the entire rock, except for the elongate sericitic stringers which correspond to the original decarbonated parts of the flowage zone. The whole recrystallized mass of the rock is strewn with microcline porphyroblasts which may reach diameters exceeding one centimeter.

Two thin sections of rocks from this zone have been examined and commented on by Professor P. BEARTH. The first is from the same La Tahona quarry. Macroscopically it is a sliver from a gray boulder measuring 50 centimeters in diameter, which grades to an almost white matrix; it corresponds thus to a dolomitic body half-way assimilated by the microcline gneiss. The thin-section shows a heteroblastic marble with quartz nests. There are also a few fine flakes of muscovite and sparse idioblasts of platy plagioclase (probably oligoclase). Some of the quartz and the plagioclase contain inclusions of carbonate. The quartz invades the carbonate mosaic with a sinuous corroding front.

The second thin-section is from the northern part of the clastic zone in the quarry south of Baruta, east of the valley. Macroscopically it represents a piece of partly recrystallized speckled flowage zone. The thin-section shows angular frag-

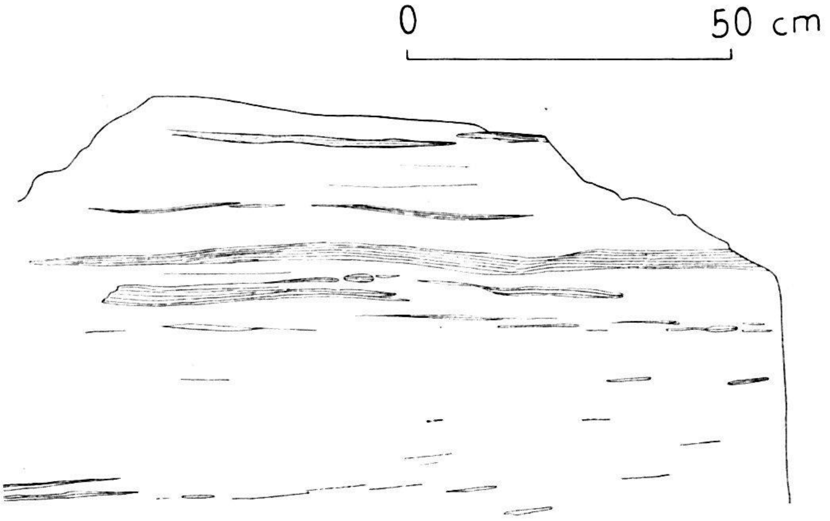

Fig. 8. The completely recrystallized homogeneous light-colored microcline gneiss with sericitic stringers.

ments of sometimes strongly pigmented carbonate, surrounded by granoblastic quartz and fine flakes of muscovite. There are also large poikiloblasts of microcline and some plagioclase with numerous inclusions; streaks of greenish muscovite in parallel intergrowth with sparse brown biotite; nests of muscovite and epidote; and a small amount of ore. Its approximate composition, exclusive of the carbonate, is 10% muscovite, 10% plagioclase, 40% quartz, and 40% potash feldspar.

These thin-sections suggest that silicates supplement the carbonate and partly replace it in the form of quartz, plagioclase, and microcline.

Figure 8 is again from the northern envelope of La Tahona quarry. It shows the final product, the almost homogeneous and white dolomitic microcline gneiss. The last remaining blotches of original carbonate are depigmented and assimilated with the homogeneous gneiss through thorough recrystallization. On the other hand, the sericitic stringers and streaks are not assimilated but remain as extraneous bodies in the gneiss. Two thin-sections have been prepared from this rock, both from the same locality. Their matrix consists of a granoblastic fabric of quartz (50%) and carbonate (50%) with a few fine flakes of muscovite. In this matrix there are inclusions of large crystals of microcline-microperthite which are partly fractured with the fractures healed by quartz and albite, less frequently by muscovite. Some of the microcline contains idiomorphic inclusions of altered plagioclase (probably oligoclase). The quartz sometimes accumulates in nests. There are intergrowths suggesting the replacement of carbonates by silicates.

5. The microcline gneiss as a metasomatic rock

Whereas in the preceding section we were mainly concerned with the presentation of observational data, this section is devoted to theorizing on the genesis of the Las Brisas microcline gneiss. Our first point is that this gneiss is the product of mechanical disintegration of the original rock and that the disintegration not only gave rise to a myriad of avenues for the migration of substances but enlarged the chemically active surface. At the same time it furnished a system of relative pressure shadows where recrystallization took place. The detailed observations show that the gneiss is essentially a metasomatic rock. Feldspars, quartz, and a part of the depigmented carbonate are the metablasts and constitute the metasome, while the dark carbonate constitutes the paleosome. As mechanical flowage and chemical migration were simultaneous, the metasomatism was syntectonic. It did not consist of molecular exchange within a rigid framework, but rather in a continuously changing one. Briefly, metasomatism was dynamic, not static.

A major problem concerns the origin of the metasomatic material. The paths of migration of the individual ions are unknown. They probably vary within wide limits. The dark carbonate probably recrystallized more or less in situ, whereas at the other extreme there may be migrations of regional extent. Thus it is probable that some of the silicate material was present as clastic admixture in the original limestone bed. Another part was presumably mobilized in the surrounding clastic sediments, especially those mechanically mixed with the dolomite during flowage deformation. Still another part may have originated in zones of higher temperature such as the zones of granitization found in the Avila range north of Caracas (DENGO, 1953).

We have demonstrated the phenomena of flowage, of mechanical destruction, and of recrystallization for the dark-colored dolomite. Exposures of this rock are excellent, and therefore the structural and metasomatic history is particularly clear. However, it may be inferred from a wealth of observations that similar processes also affected other members of the Las Brisas "formation", such as the sericitic-graphitic and the quartz-mica schists. They all exhibit flowage phenomena, they are intensely kneaded, and they contain numerous rocks with an undoubtedly metasomatic origin.

All these phenomena suggest that large relative movements have rearranged the whole series of rocks, disrupting original sedimentary contacts and replacing them by tectonic ones. In this mechanically rearranged complex molecular diffusion along and across the tectonic boundaries took place. Carbonate moved outward, away from the dolomite, silicates and quartz moved inward, into the dolomite. By this process the mechanical mixture was welded again into a new lithologic unit resembling an original sedimentary unit. The material constituting the gneiss was derived from the dolomite, the graphitic-sericitic schist, and the quartz-mica schists or the unmetamorphosed equivalents of these rocks, with the addition of molecules brought in during the course of regional migration. Briefly, the microcline gneiss is the product of combined mechanical and metasomatic rearrangement within the crust.

Of especial interest are the previously mentioned analogies with granitization phenomena. The chemical composition of the material is different, yet the morphologic phenomena are strikingly similar, and their development can be traced through virtually all transitional stages. Most of the terms used for the description and classification of migmatites can be applied to the microcline gneisses if those terms are conceived of as purely descriptive, without their usual genetical connotation. Take for instance the drawing of a migmatite shown by BARTH (1952, p. 365). It strikingly resembles the zones of dolomite relics with their envelope of microcline gneiss. BARTH's fragments of amphibolite–the paleosome–correspond to the relics of our dark dolomite, while his pegmatite–the metasome–is equivalent to the Las Brisas microcline gneiss. As protrayed in Figure 7, an example of nebulitic anatexis might be recognized, with the diffuse remnants of dark dolomite forming the skialiths (BARTH, 1952, p. 366). It is evident, however, that all these flowage and diffusion phenomena took place in the solid state, without participation of a molten phase.

Besides these analogies with migmatites, there are also similarities of the Las Brisas microcline gneiss with certain other granitic rocks, containing relic structures which are often interpreted as original sedimentary phenomena. It is therefore intriguing to observe the occurrence of pseudo-sedimentary flowage structures such as pseudo-pebbles and pseudo-crossbedding in the intermediate stages of the formation of the microcline gneiss. Were it not for the fact that all transitions can be observed these structures might be considered as original sedimentary ones, and it might be concluded that the metamorphism affected an original sedimentary sequence bodily, without large-scale previous and concomitant deformation. For granites with apparent sedimentary relics often a static granitization is assumed, but it is evident that great care in the genetic interpretation of all these relic structures must be exercised.

The evidence of the successive stages in the development of the microcline gneiss demonstrates further that layered metamorphic rocks need not be equivalent to a stratigraphic succession. It also shows that the occurrence of fossils in metamorphic rocks does not exclude intense mechanical destruction and flowage as suggested by BUCHER (1953) because flowage is a selective process; it spares massive or only slightly deformed relics of the original rock.

6. The tectonics of the Baruta zone

The structure of the carbonate zones and the mode of formation of the microcline gneisses leave no doubt that the entire zone of Baruta has been extremely mobile. The mechanically competent rocks were rolled out or ground up. The dolomitic microcline gneisses have the superficial appearance of an extremely competent, tectonically but slightly affected series (SMITH, 1953), but in reality they are secondary rocks grown from flowage zones.

If we look for typical rocks which could help us in an attempt to disentangle the tectonics, our interest will focus on the dark carbonate. We consider it a reasonable working hypothesis that all the remainders of the dark carbonate are stratigraphically equivalent, although further knowledge will probably modify this assumption. On this basis, how can we reconstruct the tectonic sequence?

There are several north dipping zones of dark dolomite with accompanying microcline gneisses piled on top of each other. The zones are discontinuous and lenticular, just as their carbonate components are discontinuous. There is frequent small-scale folding, yet the general aspect is rather one of piled-up tectonic lamellae, rolled and drawn out in the course of movements. The tectonic processes leading to such a structure were probably not simple thrusting but kneading and interpenetration of different elements of the original stratigraphic sequence. This is a large-scale equivalent of what is revealed by the flowage zones in Figure 6.

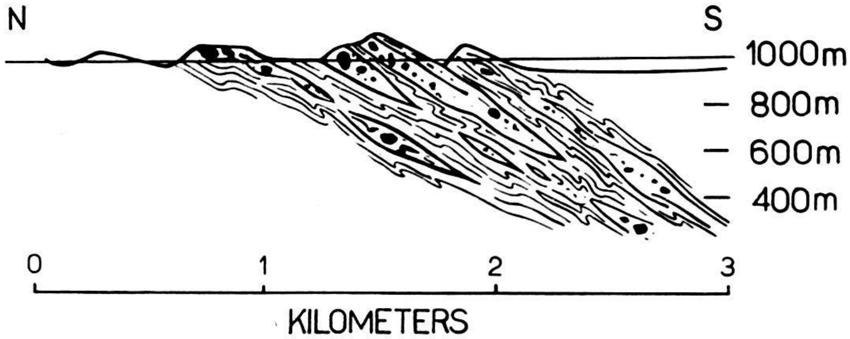

Fig. 9. Schematic cross-section through the Las Brisas "formation" in the north limb of the Baruta "anticline". For location of the section see Fig. 2.

We arrive thus at the concept of regional flow expressing itself throughout from microscopic to regional dimensions. Its essential aspects are the same throughout: closely spaced surfaces of gliding, relatively resistant *boudins* and lenses, and recrystallization. A schematic cross-section through the area is shown on Figure 9. It is schematic since the actual complications at depth cannot be extrapolated. The cross-section shows the northern limb of the Baruta "anticline" (AGUERREVERE & ZULOAGA, 1937; DENGO, 1953; SMITH, 1953).

This flow-type structure compares well with that of other parts of the Venezuelan Coast Range. Everywhere in the metamorphic belt, and even in some unmetamorphosed areas, there are indications of a similar complexity.

7. The general tectonic aspects of the Baruta zone

What are the principles governing such a chaos? The variability of movements in time and space has an opportunistic aspect. It corresponds to the principle of the path of least resistance known in fabric analysis and is contained in the following general notion which is not new but often underestimated:

The compressive tectonics at the earth's surface are largely shaped by the evasion of masses into free space. The substitute of free space at depth, below an overburden of several kilometers, is a sort of "internal free space". This term is used here to symbolize the complex set of conditions arising from the inhomogeneity of the sequence of rocks, and the complicated boundaries of the space where movements take place and produce other complicated systems such as the distribution of pressure, of ruptures, and of differential movements. The ever changing system of ruptures and of minima of pressure constitutes a kind of "internal free space". It governs the internal movements of evasion, mechanical as well as chemical. Its complexity causes the chaotic aspect of the Baruta zone.

8. A comparison with similar tectonic features in the Alps

In the Swiss Alps a striking example of these tectonics may be found in the Inneres Faflertal, in the higher part of the Lötschental. Here the thin sedimentary wedge known as "Jungfraukeil" penetrates the crystalline rocks of the Aar massif. The content of this wedge was subjected, in its evasive movements, to rigid external restrictions. Correspondingly the stratigraphic elements and the forms in which they occur are thoroughly and chaotically mixed. The "Jungfraukeil" has been described by COLLET (1947), but his description does not convey a true impression of the incredible complexity.

Alpine geologists will further be especially interested in the structural analogies between the Venezuelan Coast Range and the Pennine system. The extremely complex picture of the Pennine nappes in the region of Zermatt developed by BEARTH (1952, 1953), which is based on many years of detailed studies, fits excellently the tectonics of the "internal free space". There are several complex zones of internal movement which dissect the classical nappes into huge lenses and *boudins*. The detailed structure of these zones of internal movement is the same as that of the flowage zones of Baruta and of the "Jungfraukeil". There is widespread albitization, and albite gneisses are the secondary rocks corresponding to the microcline gneisses of Baruta.

Zusammenfassung

Die Gegend von Baruta südlich Caracas im venezolanischen Küstengebirge ist gekennzeichnet durch meist leichtgradig metamorphe Gesteine, die in mancher Hinsicht denen des Penninikums ähnlich sind. Es handelt sich vornehmlich um graphitisch-serizitische Phyllite und Schiefer und Quarz-Glimmerschiefer mit linsen- und blockförmigen Einlagerungen von dunkelgrauen Karbonatgesteinen (Dolomiten und dolomitischen Kalken und Marmoren) sowie von karbonatischen Mikroklingneisen. In diesen karbonatischen Gesteinen sind zahlreiche Steinbrüche angelegt, die detaillierte Beobachtungen über Petrogenese und Tektonik erlauben. Es zeigt sich, dass die dunklen Karbonatkörper tektonische Formen sind – Linsen, Boudins und Rollblöcke. Sie sind massive Relikte einer wohl ursprünglich zusammenhängenden Kalkbank, die im Verlauf der tektonischen Bewegungen zum grossen Teil ausgerieben wurde. Die massiven Relikte sind nun umflossen von diesen Zerreibungsprodukten sowie von den umgebenden Phylliten und Schiefern und von Gesteinen, die durch metasomatische Vorgänge sekundär entstanden sind. Mehrere Ordnungen von Fliesszonen können unterschieden werden: die grösseren Relikte sind von Fliesszonen umgeben, die ihrerseits Relikte kleineren Ausmasses mit umgebender Fliesshülle enthalten, usw. Ausserdem treten Relikte verschiedener Generationen auf: Rekristallisation in den Fliesszonen führt zu örtlicher Versteifung, und solche versteifte Fliesszonen werden erneut zerrieben, wobei massive Relikte zweiter und höherer Generationen übrigbleiben. Aus den Fliesszonen entwickelt sich durch Depigmentierung und metasomatischen Ersatz von Karbonat durch Quarz und Feldspat ein meist hellfarbener karbonatischer Mikroklingneis.

Aus der Verteilung der Züge von karbonatischen Linsen und Mikroklingneisen lässt sich schliessen, dass die Tektonik durch mehrere übereinanderliegende, diskontinuierliche Linsen und Schuppen charakterisiert ist. Man hat jedoch den Eindruck, es handle sich weniger um eigentliche

Überschiebungen als um eine Durchknetung und Ausreibung der ganzen Gesteinsserie mit ähnlichen Fliess-Strukturen von mikroskopisch kleinen bis zu regionalen Ausmassen. Diese Gesteinsserie darf demnach nicht als stratigraphische Folge angesehen werden; vielmehr handelt es sich um einen lithologischen Komplex, der durch mechanische und metasomatische Umlagerung entstanden ist.

Ein solch chaotischer Bau lässt sich verstehen aus der Kompliziertheit der Fliessbewegungen in den tieferen Teilen der Kruste, wo Ausweichbewegungen in den freien Raum verhindert sind. Die Ausweichbewegungen der mobileren Substanzen und Phasen (mechanisch wie chemisch) sind durch ein kompliziertes und zeitlich veränderliches System von Druckminima und Rupturen bestimmt, das man als „inneren freien Raum" bezeichnen könnte.

Ähnliche Vorgänge scheinen auch in den Alpen eine grössere Rolle gespielt zu haben, z. B. im Zermatter Penninikum.

References cited

AGUERREVERE, S. E., and ZULOAGA, G. (1937): *Observaciones geológicas en la parte central de la Cordillera de la Costa, Venezuela.* Bol. Geol. y Min., 3–22.

BARTH, T. F. W. (1952): *Theoretical Petrology* (John Wiley & Sons, Inc. New York.)

BEARTH, P. (1952): *Geologie und Petrographie des Monte Rosa.* Beitr. geol. Karte Schweiz, [N. F.], 96. Lfg.

– (1953): *Erläuterungen zu Blatt 535 Zermatt des Geologischen Atlas der Schweiz 1:25000.*

BUCHER, W. H. (1953): *Fossils in metamorphic rocks: a review.* Bull. geol. Soc. Amer., *64*, 275–300.

COLLET, L.W. (1947): *La géologie du versant Sud du massif de Gastern.* Eclogae geol. Helv., *40*, 257–281.

DENGO, G. (1953): *Geology of the Caracas region.* Bull. geol. Soc. Amer., *64*, 7–40.

RAMBERG, H. (1952): *The origin of metamorphic and metasomatic rocks.* (The University of Chicago Press, Chicago.)

SMITH, R. J. (1953): *Geology of the Los Teques–Cua region.* Bull. geol. Soc. Amer., *64*, 41–64.