THE LOWER GONDWANA IN ARGENTINA

JOAQUAIN FRENGUELLI
University of Buenos Aires

THE existence in Argentina of strata chronologically and palaeontologically equivalent to those of the Indian Lower Gondwana has been known at least since 1895, when Bodenbender discovered the Totoral Beds on the eastern slope of the Sierra de los Llanos in La Rioja Province, bearing remains of *Glossopteris* flora. Later on Stappenbeck, Keidel, Du Toit and others afforded data of the highest significance but, for a long time, however, divers circumstances impaired their exact interpretation both from a stratigraphical and chronological points of view. The main drawback was, undoubtedly, Bodenbender's proposal of the name " Estratos de Paganzo " for the whole thick system of beds, and its subdivision into two " pisos " or stages, the older considered as " permo-carboniferous " and the younger as " permo-triassic ". Another important drawback was the original inaccurate definition of the whole group and of its " pisos ", which led to very different stratigraphical usage of the term " Paganzo System " by Bodenbender, Keidel, Du Toit, Hausen, Trümpy and others. Serious difficulties also arose from the deficient or inexact determination of plant-remains, often too fragmentary or imperfectly preserved to be identified with any degree of confidence, as well as from an inaccurate separation of the fossils belonging to different plant-bearing deposits. To the latter deficiency must particularly be imputed the erroneous conclusion that " Piso I " (Lower Paganzo) contained a mixed flora, formed by some typical members of a northern or cosmopolitan flora associated with plants of the southern or Gondwana flora ; a conclusion which led to the conviction that this mixed flora belonged to a stratigraphical complex of Lower Permian age (Keidel) or, at most, to an Upper Carboniferous level immediately below the basal Permian (Du Toit).

Modern investigations, however, reveal instead that Bodenbender's so-called " Piso I " is truly formed by a very thick group of continental beds, the age of which ranges from Upper Devonian to the end of the Carboniferous. Recent field explorations have also shown that the " Piso II " of the same author represents a potent stratigraphic complex embracing the whole Permian period, perhaps with a Sakmarian base.

On the eastern slopes of the Precordillera of San Juan and Mendoza and around the pre-Cambrian crystalline massives of the Sierras, particularly in La Rioja, " Piso I ", the total thickness of which is not less than 2,500 metres, forms a continental complex actually divisible into five distinct units, each characterized by peculiar rocks and fossils. For them I proposed the terms Guandacol, Cortadera, Tupe, Arroyo Salamanca and Agua Colorada beds, respectively.

The lowest stage, or Guandacol beds, generally strongly unconformable over the crystalline pre-Cambrian rocks, but sometimes resting on older marine Palaeozoic tilted deposits (Ordovician limestones, Lower Devonian shales, etc.), attains 1,000-1,500 metres in thickness. When its base is exposed, it begins with a sometimes coarse tillitic basal conglomerate, followed by very thin-bedded (varvic) shales alternating with grayish and often micaceous sandstones, sometimes with small pebbles, gray-green slates, mudstones and greywackés. They grade upwards into a group of hard grayish quartzitic sandstones and fine-grained slates with ripple-marks, annelid markings and plant-remains. These last are ordinarily poorly preserved but apparently include species of *Dawsonites*, *Cyclostigma*, *Pseudobornia* and other Devonian genera.

The group just described is conformably overlain without a break by the Cortadera beds, which, as a rule, begin with a layer of sandstone, sometimes pebbly. Their prevailing rocks, however, are gray-green clay-shales and fine-grained sandstones, with intercalated black carbonaceous shales and coal seams often yielding abundant plant-remains. Casts of *Cyclostigma* and *Lepidodendron* are found in the sandy beds, while the carbonaceous clay-shales carry species of *Adiantites*, *Aneimites*, *Rhacopteris*, *Eremopteris*, *Neuropteridium*, *Sphenopteridium*,

Calamites and casts of *Lepidodendron australe* M'Coy.

The successive Tupe beds consist chiefly of grayish to greenish-gray shales and mudstones with intercalated layers of yellowish sandstones. The light, grayish sandstones of its lower portion contain, in places, intercalated layers of either tillitic conglomerates or pebbly fluvio-glacial sandstones ; but the main bulk of the beds consists of an unbedded light gray boulder mudstone containing scattered striated pebbles. There cannot be the slightest doubt that this deposit is a true ground moraine. Above the glacials, carbonaceous shales and coals, green slaty beds, and sometimes even layers of hematite carry more or less abundant plant-remains belonging to *Calamites peruvianus* Goth., *Lepidophloios* sp. and *Rhacopteris ovata* (M'Coy) Walk.

The overlying Arroyo Salamanca beds are mostly formed by coarse, yellowish-gray micaceous sandstones with some intercalations of finer grained plant-bearing layers containing, in places, casts of *Lepidodendron* and impressions of *Neuropteris* sp. aff. *N. auriculata* Brongt. and species of *Sphenopteris* of the *S. obtusiloba* Brongt. and *S. trigonophylla* Behr. groups.

Finally, the uppermost or Agua Colorada beds consist of pink to reddish arkoses, sandstones and shales often intercalated with gray and greenish mudstones, very fossiliferous in places. It is noteworthy that, in Argentina, the first members of the Gondwana flora make their appearance within these beds. At first they show up with only a few species associated with many survivors of the older cosmopolitan Lower Carboniferous flora ; but gradually, as higher and higher levels are met with, they become more and more abundant whilst, at the same time, the number of the older cosmopolitan types progressively diminishes, both as to species and individuals. Among the principal representatives of the earliest new southern flora are species of *Gondwanidium* and *Noeggerathiopsis*, already present at the basal part of this stage, while *Glossopteris* and *Gangamopteris* appear close to the end of the stage and almost at the beginning of the Permian.

The Cortadera, Tupe, Arroyo Salamanca and Agua Colorada beds show that they integrate a continuous and perfectly conformable series apparently embracing the whole Carboniferous period.

The Cortadera beds, lying directly upon the seemingly Upper Devonian Guandacol and being well enough characterized by its plant-remains and, chiefly, by *Lepidodendron australe* M'Coy, seem to correspond quite closely to the similar earliest Carboniferous rocks which, in East Australia, also bear remains of the same *Lepidodendron* and overlie a well-defined fossiliferous Devonian.

The Tupe beds, from which abundant specimens of *Rhacopteris ovata* (M'Coy) Walk. and other plants of the *Rhacopteris* flora can be obtained, may be readily parallelized with the Thabo stage of the Lower Carboniferous Po series of Spiti in India, and with the glacial stage of the Kuttung series in New South Wales, synchronized with the late Lower Carboniferous time ; both in India and in Eastern Australia these beds are characterized by their *Rhacopteris* flora. The strong similarity of the Tupe beds with the homologous strata of East Australia is emphasized by the fact that, in both regions, *Rhacopteris ovata* seems to be closely connected with glacial deposits.

As regards the Arroyo Salamanca beds, there cannot be any doubt, in my opinion, regarding the Westphalian (Middle Carboniferous) character of its flora. If this is true, and since not even traces of a southern flora have been found hereto in these beds, we should draw the striking conclusion that in Argentina the Gondwana flora did not appear before the end of the Westphalian or, perhaps, at the beginning of the Upper Carboniferous (Stephanian).

We can state with confidence that only in the Agua Colorada beds and its equivalents, exposed in the Sierras and the Precordillera, the mixed flora occurs which Keidel, Du Toit, Kurtz and others frequently mentioned. Their age ranges from the base to the top of the Stephanian, or, at least, up to the end of the Gshelian. Obviously, therefore, considerable weight must be attached to this verification, since it furnishes a key to the solution of many problems, long discussed but never satisfactorily explained. In the first place it proves that, in Argentina, two distinct plant-bearing groups are found: one exclusively characterized by cosmopolitan Carboniferous (pre-Gondwana) forms and the other bearing a mixed flora, composed of survivals of the latter associated with Gondwana types. Secondly, it shows that both these groups must be assigned to the Carboniferous, i.e. to the lower-Middle and to the Upper Carboniferous respectively. Finally, it proves that, as far as Argentina is concerned,

the sequence of palaeogeographic events from which the formation and isolation of Gondwanaland arose coincided with either the close of the Westphalian or the beginning of the Stephanian.

It might be remarked, moreover, that this interpretation invalidates the opinions of both Bodenbender and Du Toit, who believed that the whole of the plant-bearing levels of this " Piso I " should be considered as pertaining to a single horizon either of Permo-Carboniferous age (Bodenbender) or basal Pennsylvanian (Du Toit). Furthermore, it gainsays Keidel's point of view, who although admitting the existence of two distinct plant-bearing groups, pre-Gondwana and Gondwana respectively, warmly sustained a Lower Permian age for the latter.

Regarding the so-called " Northern forms " reported by Du Toit and other authors from the Lower Gondwana vegetation in Argentina and other parts of Gondwanaland, attention may be drawn to the several species which were once identified with similar European Carboniferous forms but that recent and more accurate determinations have proved to be different and peculiar species of the southern hemisphere. Actually, these have now become so numerous as to make wholly evident Sahni's suggestion that such " northern types ", generally considered as migrants from the north, may be more naturally regarded as southern survivors or descendants from the cosmopolitan life of pre-Gondwana times.

For the distinction of the above-mentioned stages, considerable importance is attached to the Quebrada de la Cortadera, on the southern side of the Cerros de Villa Union in La Rioja Province, since this ravine displays the only complete section known up to now. In all other localities, even near La Cortadera, one or several members of the series are usually missing. In the adjoining Tupe ravine, for example, and in the well-known section of the Guandacol hill originally described by Bodenbender, the Agua Colorada beds are completely lacking and a succession very similar to that known in Eastern Australia is displayed, where, owing to the interposition of a strong break, the base of the Kamilaroi (Permic) system directly overlies the Kuttung series. Instead, on the east of the Sierra de los Llanos, in the south of La Rioja Province, directly overlying the crystalline schists of the range, only the upper member of Bodenbender's " Piso I ", i.e. the Agua Colorada beds of the Cortadera section, are fully developed, while the lower members are either little developed or entirely missing. This difference, which has led to so many incorrect interpretations, depends exclusively on the fact that these deposits were not accumulated within a single huge basin but in several smaller down-warps, where deposition did not begin simultaneously but in successive stages within the belt of Hercynian folds and overthrusts. It should be noted, moreover, that the tectonic and sedimentary evolution of these down-warps, or secondary basins, even if closely similar does not appear to be identical in all cases from mid-Palaeozoic times to the present.

The sections displayed further to the west, along the western slopes of the Precordillera, are of even greater significance for the age determination of the above-mentioned horizons, as here fossiliferous marine deposits are found intercalated between the continental sediments. These attain greater importance in the Barreal (San Juan) region, chiefly in the ravines of El Salto, Arroyo Cabeceras and Leoncito Encima, where Stappenbeck and Keidel and Harrington discovered the Carboniferous beds from which Du Toit and Cowper Reed also reported fossils. The two upper horizons discussed by the last named authors really belong to a single stage, which, as a whole, corresponds to Stappenbeck's " piso del *Spirifer supramosquensis* ". It can be ascribed, without hesitation, to the Upper Carboniferous, as was originally done by Stappenbeck and, according to Du Toit and Cowper Reed, probably to the base of the Upper Carboniferous ; perhaps more exactly, I should say, to the Gshelian.

The lower marine horizon, found at the base of the same section, lies upon glacial deposits with true tillites. At Leoncito Encima, Keidel and Harrington found, in these strata, species of *Syringothyris*, *Cyrtospirifer* and other lower Carboniferous brachiopods and even frequent plant-remains including *Rhacopteris ovata* (M'Coy) Walk. Keidel and Harrington have stated that the Lower Carboniferous age of these beds is well defined by its marine fossils and plant-remains (1938), while Du Toit admits that the Leoncito Encima tillites, with intercalations yielding *Syringothyris* and *Cyrtospirifer*, can be considered as Visean (1937).

For the purpose of establishing stratigraphic relationships and chronological determinations

it might, therefore, be concluded that the upper marine beds of the Barreal district correspond to the Agua Colorada beds of the Cortadera ravine, while the lower marine beds of the same area, bearing *Syringothyris keideli* Harr. and *Rhacopteris ovata* (M'Coy) Walk., can be synchronized with the Tupe continental beds of the Cortadera region. Finally, the sediments of a continental character, with abundant plant-remains (badly preserved and not yet studied), which at Barreal are found between the two marine horizons, seem to be the equivalent of the Arroyo Salamanca beds of the Cortadera section.

Strong evidence in favour of this conclusion is also afforded by the occurrence, at the Herradura ravine in the Sierra de Perico, to the NNE of Jáchal (near the Cerro de Guandacol and Cortadera ravine), of the same lower marine level with *Syringothyris keideli* Harr. overlying the Cortadera beds with *Lepidodendron australe* M'Coy. In this place, apparently at the extreme eastern border of the Visean transgression, the *Syringothyris*-bearing strata correspond to either an estuarian or lacustrine assemblage in which marine lenses are interbedded with thin beds carrying species of *Carbonicola*, continental plant-remains and coals. It is of further interest that in this section, as in the Tupe ravine (La Negra mine), the plant-bearing beds yielding remains of the *Rhacopteris* flora overlie a glacial deposit presumably comparable to the Glacial stage of the Kuttung series in New South Wales.

In connection with this problem, it must be made clear at the very outset that the Tupe glacial deposit should not be confused with the basal glacials of the Guandacol beds. This has been inaccurately done in the past, and all the Precordilleran glacial deposits have either been mixed up in a single unit or considered as three distinct levels within a single stratigraphic series. In reality, at the eastern foot of the Sierra Chica de Zonda, noticed by Keidel and Du Toit, as well as in every similar section in other parts of the Precordillera and Sierras, the main glacial deposits belong to the pre-Gondwana and must be assigned to two principal glacial phases : the first at the base of the Guandacol beds, the second corresponding to the Tupe beds. The first, surely of greater importance and duration on account of its conspicuous thickness, contains, in its upper part, shaly intercalations with *Dawsonites* and, hence, is seemingly of Upper Devonian age ; the second, represented by thinner and less extensive glacial sediments, corresponds, owing to its close relationships with the *Rhacopteris* flora, to the Visean time.

Though of minor significance, Gondwana glacial deposits undoubtedly also occur in the same localities, but they appear at higher stratigraphic levels, namely, in the later stages of the Upper Carboniferous Agua Colorada beds (or its equivalents) and, as will be seen presently, even during the Permian. As regards their stratigraphical position, they can be correlated with the Indian Talchir and Damuda glaciations, respectively. Owing to their slight development and extension, their several exposures were hitherto unknown to most geologists, notwithstanding the fact that one of these deposits, made up of Upper Carboniferous glacials, outcrops at the base of the well-known plant-bearing beds of Bajo de Velis (San Luis) with *Gondwanidium*, *Noeggerathiopsis*, *Gangamopteris* and *Rhipidopsis*, as well as at the top of the classical profile of Retamito (San Juan), with *Lepidodendron*, *Calamites*, *Gondwanidium* and *Botrychiopsis*, where they were erroneously correlated with the European Culm.

Concerning the whole of these glacial deposits, it is important to note that in Argentina, as far as we know, wherever they appear they do not show indications of having been deposited by a glacial cap as that which covers at present vast tracts of the southern Patagonian cordillera, but, instead, suggest the existence of mountain glaciers like those found in the higher peaks of the temperate zones of the earth. In all recorded instances, the pre-Gondwana tillites, and even the largest bodies of ground moraines, are always found in long and rather narrow basins, often widely separated from each other. Furthermore, over the true tillites, and chiefly in the thinner Gondwana glacial deposits, fluvio-glacial conglomerates and varved glaci-lacustrine shales predominate.

As regards " Piso II " of Bodenbender's Paganzo System, recent field explorations have not led to much improvement of our stratigraphical knowledge and it is still considered as a thick series of continental red clays and sandstones forming a stratigraphically indivisible unit, for which I have proposed the collective term " Patquía beds ". This series, the total thickness of

which is probably not less than 1,500 metres, begins in some places with a basal conglomerate, sometimes chiefly composed of subrounded amygdaloid basaltic fragments, pebbles and grits, resting transgressively on the Agua Colorada beds, or else on the Tupe beds, and ends beneath unconformably-lying augite-porphyrite flows, breccias and tuffs or sandstones of Lower Triassic age.

It should be taken into consideration, however, that within this sequence two fossiliferous levels of the highest significance have been lately discovered: one just at the base of the series, the other at the top of its lower division. The lower level corresponds to the so-called "Totoral beds", originally described by Bodenbender in 1895 and since then much discussed. Recent investigations, which brought about the discovery of wider exposures along the eastern flank of the Sierra de los Llanos in La Rioja, have corroborated and somewhat more precisely defined the older data about the existence of *Barakaria dichotoma* (Fst.) Sew. et Sahni in these basal beds. At the foot of a ravine in the neighbourhood of the village of Unquillal, a number of specimens of *Barakaria dichotoma* (Fst.) Sew. et Sahni, associated with *Gondwanidium argentinum* (Kurtz), *Noeggerathiopsis Hislopi* (Bunb.) Fst. and a new species of *Walchia* have been recently collected in a hard, greenish clay-shale. It is really striking that the same species of *Barakaria*, during the lapse of almost a century, has been found only in the Barakar beds of India and in the Totoral beds of Argentina; so much so, that one cannot avoid the conclusion that the Totoral beds, at the base of the Patquía series, represent the stratigraphical and chronological equivalents of the Barakar beds at the base of the Damuda series. It must, therefore, be inferred that if the Barakar in India marks the beginning of Permian events, the Totoral marks the oldest Permian time in Argentina. It may be recalled that already Keidel placed these Totoral beds in the Lower Permian, but at the end of this period, that is to say, at the top of his Catuna beds. At the present, however, it can be affirmed that, excluding the Totoral beds, Keidel's remaining Catuna beds coincide exactly, as a whole, with the Agua Colorada beds of Upper Carboniferous age. Actually, in the Sierra de los Llanos in La Rioja, the uppermost portion of the latter beds, just beneath the strata with *Barakaria*, are represented by layers containing species of *Calamites*, *Lepidodendron*, *Gondwanidium* and *Gangamopteris*, namely of *G. cyclopteroides* Fst.

The other fossiliferous level of the Patquía series has been found on the Cerro Colorado de la Antigua, about 50 miles south-eastward of La Rioja city, in the upper part of the lower section of the whole sequence. This consists of an assemblage of fine-grained, clayish-gray sandstones with concretions of marlekor type and remains of *Dadoxylon* wood, followed by thin-bedded, varved (glaci-lacustrine) shales with numerous shells of *Palaeoanodonta*. The *Dadoxylon* exhibits well-marked growth-rings; the *Palaeoanodonta* belong to a species closely allied to *P. okensis* Amal. and even to *P. stocleyi* Cox from the Ruhembe beds of the African territory of Tanganyika, which Cox placed immediately beneath the Upper Permian beds of the same region. Evidently this assemblage, of an unmistakable glacial nature, can be assigned to the top of the Lower Permian series.

It seems that we must also correlate with the same beds the Sauce Grande glacial stage of the Sierra of Pillahuincó in the southern range of the Sierras of Buenos Aires. As Harrington has noticed (1947), the Sauce Grande beds are formed by a sequence of hard tillites and slaty mudstones in its upper part, containing remains of the pelecypod genus *Astartella* and, through a conformable transitional set of beds, passing up into the Bonete beds, with the cool-water pelecypod genus *Eurydesma* and *Glossopteris indica* Schimp., *Glossopteris angustifolia* Brongt., *Gangamopteris cyclopteroides* Fst. and other plants of an "unmingled" *Glossopteris* flora. The tillites of the Sauce Grande series may be correlated with the Lochinvar glacial beds of New South Wales, assuming that the latter correspond to the Lower Permian as Schuchert (1932) believes.

In connection with the climatic relation of the Gondwana flora in Argentina, it is suggestive that, as far as we know, this flora made its appearance long after the greatest Lower Carboniferous glaciation, that is, during Upper Carboniferous time. But the same flora increases and settles down just after the intra-Agua Colorada glacial level, seemingly equivalent to the Talchir glacial beds of India; finally, a "pure" *Glossopteris* flora, that is to say, without admixture of older cosmopolitan survivors, grows after the glacial beds of Sauce Grande were deposited. It is noteworthy

that farther northwards the glacilacustrine sediments of Cerro Colorado de la Antigua are found intercalated among red strata, a greater part of which are sandstones with aeolian (dune) texture, indicators of a warm and rather arid climate. Another striking fact is that *Dadoxyla*, the only trees known in this formation, clearly present well-marked growth-rings, showing that the climate also had well-marked seasons. This fact is in itself suggestive evidence that our Carboniferous and Permian glacial deposits are not related to a large ice-sheet and, perhaps, not even to a true glacial epoch, but merely indicate a period of a relative descent of temperature followed by an increase of atmospheric humidity, that is to say, of nival precipitation in the high mountains.

Regarding the upper boundary of the Patquía series, contrary to what has already been suggested, it can now be affirmed that the upper beds do not pass into the Triassic, but that the accumulation of the series came to an end at the close of Permian times. My own recent investigations tend to demonstrate, on good grounds, that soon after the sedimentation of the Patquía beds (or Bodenbender's " Piso II " of the Paganzo system), Triassic events were initiated, beginning with Lower Triassic eruptions of vast masses of volcanic material (augite-porphyrite, quartz-porphyries, eruptive breccias and tuffs), followed by the so-called " Rhaetic beds ", that is to say, with a thick succession of sandstones, shales and carbonaceous mudstones carrying the so-called *Thinnfeldia* (*Dicroidium*) flora, and ranging from the mid-Triassic to the Keuper and, also, to the Rhaetic.

SUMMARY

The existence of formations in Argentina comparable to those of the Lower Gondwana of India has been known since 1895, but their more exact knowledge is of recent date. At first, G. Bodenbender, their discoverer, thought that all the thick stratigraphic complex which he called " Terreno de Paganzo " and which he divided into two stages, or " pisos ", that is " Piso I ", considered Permo-Carboniferous, and the second, " Piso II ", attributed to the Permo-Triassic. Recent discoveries have demonstrated, however, that Bodenbender's Paganzo comprises a whole system ranging from the earliest Carboniferous (perhaps with an Upper Devonian base) to the end of the Permian. Throughout the thickness of " Piso I " five levels could be recognized; these are, in decreasing order of age: Guandacol beds, containing *Dawsonites* and *Cyclostigma*; Cortadera beds, with *Lepidodendron australe*; Tupe beds, with *Rhacopteris ovata*; Arroyo Salamanca beds, with *Neuropteris* and *Sphenopteris* of Westphalian type; Agua Colorada beds, in which, along with the last survivors of a cosmopolitan Carboniferous flora, the first elements of a Gondwana flora appear. Only within the last named level, which can be considered as of Upper Carboniferous age (post-Westphalian), does that mingled flora come into its own and whose interpretation caused Bodenbender, Wite, Keidel, Du Toit and other authors so much concern. In the former levels, however, surely pre-Gondwanic, only the remains of a previous cosmopolitan Carboniferous flora could be recognized and with no mingling of Gondwanic elements. In the Agua Colorada beds (Upper Carboniferous), the first representatives of the new southern flora were species of *Noeggerathiopsis* and *Gondwanidium* to which, later, were added species of *Gangamopteris*, *Glossopteris* and other types of the Gondwana flora. But a " pure " *Glossopteris* flora, that is, with no mingling of former cosmopolitan elements, is only to be attained in the overlying " Piso II ", to be considered of Permian age throughout. It is noteworthy that this " Piso II ", which on the whole may come under the heading of Patquía beds, begins with a series of strata (the Totoral beds) which contain many specimens of *Barakaria dichotoma*, that is to say, remains of the same plant that, in India, characterizes the Barakar stage at the base of the Damuda series.