ISSN (print): 1698-6180. ISSN (online): 1886-7995
www.ucm.es/info/estratig/journal.htm

Journal of Iberian Geology 34 (1) 2008: 123-158

Journal of
Iberian Geology
AN INTERNATIONAL PUBLICATION OF EARTH SCIENCES

The Permian-Triassic transition: Historical review of the most important ecological crises with special emphasis on the Iberian Peninsula and Western-Central Europe.

La transición Permo-Triásica: Revisión histórica de la crisis ecológica más importante con especial énfasis en la Península Ibérica y Europa Central y Occidental

C. Virgili

Departamento de Estratigrafía, Instituto de Geología Económica, UCM-CSIC.
Facultad de Ciencias Geológicas. Universidad Complutense de Madrid. C/ Antonio Nováis 2, 28040 Madrid, Spain.
carmina.virgili@gmail.com

Received: 16/09/06/Accepted: 23/01/07

Abstract

One of the most important climatic and biological crises of the history of the Earth occurred 250 m.a. ago, during the transition from the Permian to the Triassic. During the Permian, all of the continental blocks were covering one hemisphere forming the Pangea supercontinent, while the other was covered by the Panthalasa ocean. General conditions for living on land were very precarious. The exuberant vegetation of the Carboniferous period had disappeared almost completely, as well as the large insects that sheltered there and many amphibians that lived in the flooded areas. There is, however, less information about the immense ocean, although the marine fauna was very abundant and varied.

The landscapes of Pangea were very varied as it comprised very diverse climatic regions. At the polar areas there were enormous ice caps while at mid and tropical latitudes there were hotter and more temperate climates. Huge areas of the immense continent, far from any marine influence, were however very arid. On the plains, ephemeral, slow-moving courses of water deposited their alluvium, while at the coastal regions, strong tides left lagoons where saline deposits were formed. Volcanic activity was important as can be seen by the great outflows of basalts and andesites as well as the pyroclasts and ashes interbedded in the deposits of the Permian.

With the start of the Mesozoic, in the Triassic, the world started to take the shape we see today. Pangea started to crack and break up heralding an important palaeogeographical change. At the end of the Permian, between 85%-95% of marine and land species had disappeared and the life forms that characterized the Mesozoic and the Cenozoic began to develop. Credence today is given to the theory that this biological crises was due to dramatic climatic change caused by the drastic appearance of volcanic eruptions that released enormous lava flows and projected clouds of dust and toxic gas into the atmosphere. The marked regression of the marine waters at the end of the Permian also contributed to this enormous extinction and the subsequent renovation of the fauna. General perturbations related to anoxia and change in temperature and biological productivity, are shown by many geochemical studies in marine sediments, in the stratigraphical series from those areas where there was continuity in sedimentation during the Permian-Triassic transition.

Extinction and later renewal is very evident in the flora of the continental series. At the beginning of the Triassic all traces of vegetation had disappeared in huge areas and it is not possible to find some sign of recuperation in the sediments (only in the form of fungus spores) until the end of the Scytian (Lower Triassic), as the return of the conifers did not happen until the Anisian (Middle Triassic).

Keywords: Permian, Triassic, extinctions, biological crises, renewal, Pangea, volcanic eruption, climate change.

Resumen

Una de las crisis climáticas y biológicas más importantes de la historia de la Tierra sucedió hace unos 250 m.a., durante la transición del Pérmico al Triásico. Durante el Pérmico, todos los bloques continentales estaban ocupando el hemisferio norte constituyendo el supercontinente Pangea, mientras que el otro hemisferio quedó ocupado por el océano Panthalasa. Las condiciones generales de vida en los continentes eran muy precarias. La exuberante vegetación del Carbonífero había desaparecido casi completamente, así como los insectos de gran tamaño que se cobijaban en ellos y los anfibios que vivían en las zonas encharcadas. Del gran océano hay, sin embargo, menos información, aunque la fauna marina fue abundante y variada.

Los paisajes de Pangea fueron muy variados, ya que comprendían regiones climáticas muy variadas. En las zonas polares había una gran cantidad de hielo acumulado mientras que en las zonas medias y tropicales los climas eran más cálidos y temperados. Las vastas áreas del inmenso continente, lejos de la influencia marina eran, sin embargo, muy áridas. En las llanuras, los cursos fluviales efímeros fueron depositando sus sedimentos, mientras que en las regiones costeras alimentaron zonas de lagoon en las que se fueron acumulando depósitos salinos. La actividad volcánica fue importante, como puede deducirse de las frecuentes acumulaciones de andesitas, piroclastos y cenizas volcánicas encontradas entre las rocas de edad Pérmico.

Con el comienzo del Mesozoico, en el Triásico, el mundo comenzó a esbozar aquel que podemos ver hoy. Pangea comenzó a fracturarse permitiendo importantes cambios paleogeográficos. Al final del Pérmico, entre un 85%-95% de las especies marinas y continentales habían desaparecido, comenzando a desarrollarse las formas de vida que caracterizarían al Mesozoico y al Cenozoico. En la actualidad hay un importante apoyo a la teoría que relaciona esta crisis con una drástica aparición de erupciones volcánicas que liberó grandes cantidades de flujos de lava e inyectó nubes de polvo y gas tóxico a la atmósfera. La importante regresión de aguas marinas que tuvo lugar a finales del Pérmico también contribuyó a esta extinción y a la posterior recuperación. Perturbaciones generales relacionadas con anoxia y cambios en la temperatura y en la producción biológica han podido ser observados mediante el estudio de sedimentos marinos en aquellas series en las que hubo continuidad sedimentaria durante la transición entre el Pérmico y el Triásico.

La extinción y posterior recuperación es muy evidente en la flora de series continentales. A comienzos del Triásico apenas quedaban trazas de vegetación en los sedimentos (sólo en forma de esporas de hongos) no siendo posible tampoco encontrar signos de recuperación hasta finales del Scytiense (Triásico Inferior), ya que las coníferas no aparecieron hasta el Ansiense (Triásico Medio).

Palabras clave: Pérmico, Triásico, extinciones, crisis biológica, recuperación, Pangea, erupción volcánica, cambio climático.

1. Introduction

One of the most important climatic and biological crises of the history of the Earth and its life occurred 250 million years ago, during the transition from the Paleozoic to the Mesozoic era, that is, between the Permian and Triassic periods. The analysis of this great crisis allows us to reflect on the climatic changes over the length of the history of the Earth, on the interrelation between living creatures and the environment and also the responsibility of humans in relation to the changes that could happen in the future.

During the Permian, the complex plate dynamics that the Hercynian orogeny produced, welded together all of the continental blocks forming a supercontinent, Pangea, that extended from pole to pole practically covering one hemisphere. The other one was covered by the sea, the immense ocean we call Panthalasa. Studies on the dating of the materials deposited in this period along with the remains of flora and fauna that they contain allows us to reconstruct quite accurately the environmental characteristics of Pangea. There is less information about the immense ocean, we only have some knowledge about the sedimentary materials deposited in the continental shelves and in marine basins where, for some time, the ocean covered the edges of the continents. Not a great deal is known about the central part of Panthalasa, as since then, it has continued to be submerged beneath the waters of the present day Pacific Ocean and almost totally subducted. The marine fauna was very abundant and varied. The majority of classes and species which lived throughout the Paleozoic still existed: trilobites, fusulines, goniatites, tetracoralaria… The conditions for life on land however were very precarious. The exuberant vegetation of the Carboniferous period had almost completely disappeared, as well as the large insects that sheltered there and many amphibians that lived in the flooded areas.

With the start of the Mesozoic, the existing world started to take the shape we see today. The geodynamic tensions of the Hercynian orogeny which had reunited all the continental blocks in the Pangea stopped and this immense continent started to crack and break up. Throughout the

Mesozoic a great fissure opened up from north to south giving rise to the Atlantic ocean and during the last 250 million years the continental blocks moved to where we find them today. On the other hand, the characteristics of the fauna and flora changed drastically between these two periods in a relatively short space of time (approximately one million years). At the end of the Permian, between 85% and 95% of marine and land species disappeared, and the life forms that characterize the Mesozoic and the Cenozoic began to develop. Among the ammonoids, the ceratites replaced the goniatites, the tetracoralaria gave way to the exacoralaria that currently continue to form the coral reefs, and other groups like trilobites and fusulines disappeared forever. Among the reptiles, a group of therapsids called "mammaloids" developed and are considered to be the predecessors of mammals. It can be said that the Triassic represents the dawn of the present day world.

Although throughout the history of the planet there have been other biological crises, the one that occurred between the Permian and the Triassic was the most important of the last 500 million years and perhaps the best studied. Several theories have been proposed to explain the cause. At first it was thought that it was due to the impact of a large meteorite or comet, but now more credence is given to the theory that it was due to dramatic climatic change caused by powerful volcanic eruptions that released enormous lava flows and projected clouds of dust and toxic gas into the atmosphere. Another very important thing, which undoubtedly contributed to this enormous extinction and the subsequent renovation of the fauna, was the marked regression of the marine waters at the end of the Permian, in part because of climatic changes but, principally because of the geodynamic processes linked to those caused by the volcanic eruptions. Their result was the emergence above water of the continental platforms where the majority of the living marine species were concentrated and, as the habitat dried out, they became extinct.

2. The Permian and Triassic in the Geological Time Scale

2.1. The Permian

More than 160 years ago, Roderick Murchison, a prestigious British geologist and president of The Geological Society of London, organised a scientific expedition to study the geology of Siberia. The expedition was sponsored by the Tsar Nicholas who was responsible for the construction of the Great Palace of the Kremlin and the first railways in Russia. Murchison had worked with Lyell in the study of the Tertiary of the Paris basin and later studied the rock formations which underlay the Carboniferous in Great Britain which in those times were poorly known. He defined the Silurian System in 1835 and the Devonian System in collaboration with Adam Sedgwick in 1839.

Murchison also made various journeys to study these rocks in Central and Eastern Europe. In 1841, near the Urals, he discovered a thick formation of red detritic materials with fossiliferous limestones in the lower layers. These materials overlay a well characterised Carboniferous formation and are covered by the Triassic which was already known to be the first Period of the Mesozoic Era and for this reason recognised that these materials were contemporaneous with the *New Red Sandstone* and *Magnesian Limestone* of his country.

In his work *The Geology of Russia in Europe and the Ural Mountains* (1845) he proposed a new Period for these rocks, named the Permian, because they were situated in the old kingdom of Permiya.

The different stages of this Period were defined for the first time near the Urals in the central Russian platform and named according to the place where they were best exposed (Dunbar, 1940; Stepanov, 1973). It was realised very soon after, however, that this decision had not been completely appropriate. While the lower levels showed a total continuity with the Carboniferous, and are formed by fossiliferous limestones, it is not the same in the upper part. These levels are made up of clays, sandstone and conglomerates with gypsum and, furthermore, contain very few fossils and its boundary with the Triassic is not at all clear. It was not, therefore, the most suitable formation for the definition of the stratotypes. Although at first it was thought that the solution could be found relatively nearby in the Caucasus, it was later realised that in this region the series between the Permian and the Triassic are also separated by adiscontinuity. The chronostratigraphic nomenclature proposed by the Russian geologists at the International Geological Congress in Moscow (1984) (Table 1) was not accepted for the Upper Permian, although this nomenclature continued to be used. After forty years of research and discussion the solution still had not been found and it would be twenty years later when a definitive nomenclature was finally agreed upon.

For many years a number of geologists searched for outcrops where the three characteristics necessary to define the stratotypes were clearly represented (Tozer 1984, 1988). These characteristics are: continuity of the succession, appreciable presence of characteristic fossils and geological and political conditions which assure accessibility. The Himalayas, Salt Range in Western Pakistan and NW Greenland all had suitable geological character-

System Period	Series Epoch	Stages/Ages
TRIASSIC		
PERMIAN	UPPER	TATARIAN
		KAZANIAN
		UFIMIAN
	LOWER	KUNGURIAN
		ARTINSKIAN
		SAKMARIAN
		ASSELIAN
CARBONIFEROUS		

Table 1.- The chronostratigraphic nomenclature of the Permian Period proposed by the Russian geologists at the International Geological Congress in Moscow (1984).

Tabla 1.- Nomenclatura cronoestratigráfica para el Periodo Pérmico propuesta por los geólogos rusos durante el Congreso Internacional de Moscú (1984).

istics but were ruled out for reasons of difficult access.

The solution was believed to have been found in China where geologists of the Academy of Science in Beijing, the University of Geoscience in Wuhan and the Institute of Paleontology of Nanjing had been studying some very interesting outcrops in the lower Yangtse valley (Yang *et al*., 1984; Yin *et al*., 2001; Mei, 1996) (Fig. 1). These outcrops are easily accessible and the Upper Permian is formed by a limestone rich in characteristic fossils: ammonoids, fusulinids and conodonts. The Lower Triassic overlays these beds in total continuity and is also formed by fossiliferous limestone. This was therefore an ideal formation to define the Upper Permian. The results of this research were officially presented at the XI International Congress of Permian and Carboniferous held in Beijing in 1987 and finally approved in 2001 by the International Commission for Stratigraphic Nomenclature (Yin *et al*., 2001). The names accepted for the two upper stages of the Permian were the Changhsingian and the Wuchiapingian, which together form the Lopingian.

This decision still did not completely resolve the problem. The succession defined at the Russian platform was suitable for the Lower Permian both for its characteristics and for its continuity with the Carboniferous. The same was true in China for the Upper Permian. But it was soon realised that something was missing between the two series. A part of the Earth's history was not represented in the proposed succession and would have to be found in another region of the world. In the Guadalupe Moun-

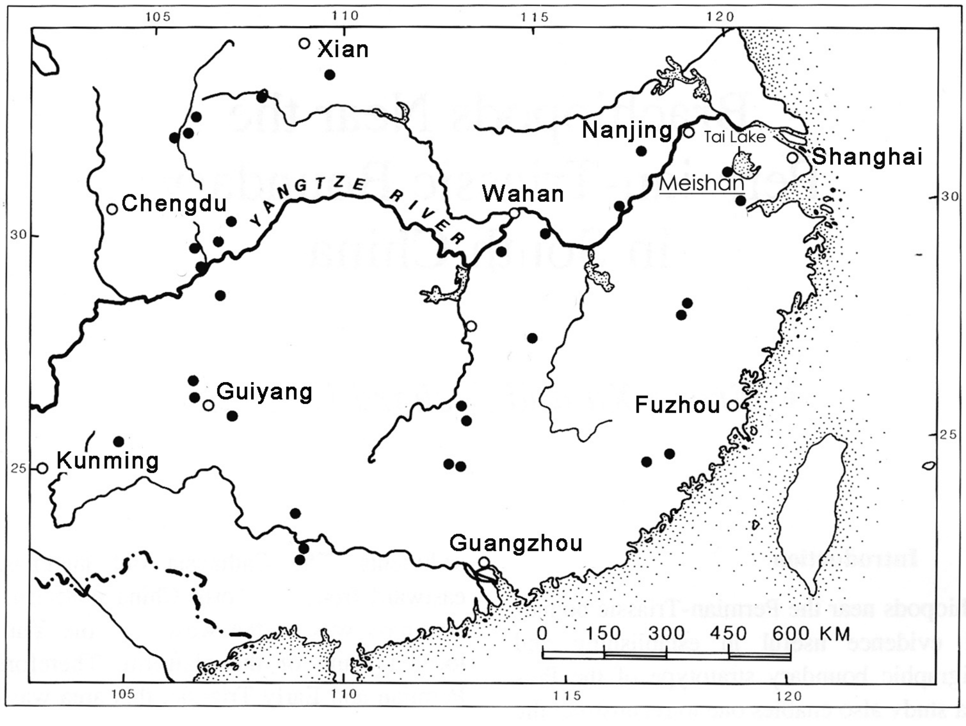

Fig. 1.- Geographical map of lower Yangtze river area, southern China. Black points represent Changxingian outcrops. The asterisk near Meishan indicates the GSSP of the Permian-Triassic Boundary. Modified from Xu and Grant (1994).

Fig. 1.- Mapa geográfico de la zona del tramo inferior del río Yangtze, sur de China. Los puntos en negro representan los afloramientos del Changxingiense. El asterisco, en las proximidades de Meishan representa el GSSP del límite Pérmico-Triásico. Modificado de Xu y Grant (1994).

Table 2.- The division of the Permian into three series approved in the International Geological Congress in Florence (2004): The Lower or Cisuralian defined in Russia, the Middle or Guadalupian defined in the USA and the Upper or Lopingian defined in China.

Tabla 2.- División del Pérmico en tres series aprobada en el Congreso Internacional de Florencia (2004): La parte inferior o Cisuraliense fue definida en Rusia, el Guadalupiense o Pérmico Medio fue definido en Estados Unidos de América, y el Pérmico Superior o Lopingiense fue definido en China.

System Period	Series/Epoch		Stages/Ages	m/years
PERMIAN	UPPER	LOPINGIAN	CHANGHSINGIAN	251.0 ± 0.4
			WUCHIAPINGIAN	253.8 ± 0.7
	MIDDLE	GUADALUPIAN	CAPITANIAN	260.4 ± 0.7
			WORDIAN	265.8 ± 0.7
			ROADIAN	268.0 ± 0.7
	LOWER	CISURALIAN	KUNGURIAN	270.6 ± 0.7
			ARTINSKIAN	275.6 ± 0.7
			SAKMARIAN	284.4 ± 0.7
			ASSELIAN	294.6 ± 0.8 299.0 ± 0.8

tains in Texas, USA, a suitable outcrop was identified. The three Middle Permian stages were defined here; the Capitanian, the Wordian and the Roadian. In fact, american geologists (Glenister *et al*., 1992) had proposed for many years the existence of a Middle Permian, but it was not accepted by european geologists as in the Eurasian block the Permian is formed by two cycles separated by an important discontinuity. It was later recognised by the international community that the hiatus that separated the two cycles could "hide" the Middle Permian. Finally, the puzzle was complete (Table 2).

This stratigraphic nomenclature is difficult to apply to continental formations, where characteristic fossils are scarce and therefore dating is more complicated. For this reason local names based on lithological characteristics are systematically used by geologists of different countries.

Only in Europe, for example, there are three different cases whose exact equivalence with marine series is still uncertain (Virgili *et al*., 1977). In Central Europe, principally in Germany and Poland, the Permian is represented by extensive outcrops with uniform characteristics and contain important mineral resources, principally copper and also the most important sodium and potassium deposits in the world. For this reason the nomenclature used proceeds from the mining industry. It has two distinct units, the lower or Rotliegendes and the upper or Zechstein. The Rotliegendes is formed by red clays sandstones and conglomerates and derives its name from Rothes Todtliegendes which means "red dead beds"(sterile red beds), as underlaying them there are coal series (Carboniferous) and covering these is the Zechstein which contains the important mineral deposits. This name means "mine rock". Its basal levels contain copper deposits and are called the Kupferschiefer (copper shales). The Zechstein is also where important potassium deposits are mined in Germany and Poland. In the Netherlands and the North Sea these rocks are in the subsurface and contain important crude oil deposits. According to the study of the microflora, the Zechstein corresponds to the Upper Permian and a part of the Rotliegendes corresponds to the Lower Permian and probably the Middle Permian is totally or in part represented by the important discontinuity which separates the two. Recent studies of the insect remains and tetrapod footprints (Gand *et al*., 2000; Schneider *et al*., 1994) will hopefully permit more precise dating.

In Great Britain two formations are defined but they do not clarify the boundary between the Permian and Triassic; New Red Sandstone and Magnesian Limestones depending on their lithological characteristics. These rocks which cover the important coal deposits are of little or no economic interest and therefore have not been studied to any great extent.

In France the situation is more complex. The Permian forms isolated outcrops with different lithological characteristics. Sometimes we find red beds with important volcanic intrusions, such is the case in the Esterel Massif of the Côte d'Azur. On other occasions we find black shales with coal beds as is the case in the Autun Basin, in the Central Massif. Given the economic interest, this area was the first to be studied and was considered it as representative of the continental Lower Permian and contemporaneous of the Artinskian by Munier-Chalmas and Lapparent (1893). It contains very characteristic macro and microflora which have also been found in other regions of Western Europe. The materials which contain this flora are considered Autunian. In the Autun basin it is not possible to observe the relationships with the underlying Carboniferous or with the upper levels. The same authors considered that the red sandy beds, in some places, are located directly on the Autunian sediments, while, in other places, these sediments are constituting the whole Permian section, representing the middle part of this system, and being named Saxonian. They did not cite any characteristic flora or reference site and, although this formation is not identified and this name has never been used in Saxony, they decided upon this name because they considered the materials equivalent to the "Saxe sandstone". Renevier (1874) had proposed the name Thuringian for the materials of the Upper Permian in France. He chose this name because he considered them to be equivalent to the sandstone and limestone of the Thuringian Wald (Thuringian Forest) which in reality are Triassic. Later on, Munier-Chalmas and Lapparent (1883) considered that this name should be maintained. The materials known as Thuringian contain typical flora from the Changhsingian which is proof that they are Upper Permian in age but no characteristic flora has been found for the Saxonian. For a long time it was believed that the Saxonian represented the Middle Permian and was characterised by an unconformity which separated it from the Autunian (Saalian orogeny). But we know today that in the Permian there are many internal unconformities which are heterochronous and are therefore not criteria for dating the stratigraphical units. The relationship between the Saxonian and Thuringian is not clear and never has been well defined (Pruvost, 1956). For this reason it is almost unanimously accepted that this name should not be used. The Thuringian and the Autunian are not cronostratigraphic units but floral assemblages with temporal significance. In any case, each day there are more doubts concerning the relation between the Autunian and Stephanian floras. It is possible that they do not always represent two different ages but only two different climatic environments that could be contemporaneous.

In Spain, as will later be seen in more detail, the Permian is also represented by isolated outcrops with similar characteristics to those of France and as such it is not surprising that the same stratigraphic nomenclature is used, despite its ambiguities.

2.2. The Triassic

The definition of the units of the Triassic was not as complicated but was just as laborious, as the different sites in Europe where its studies began had very different characteristics.

The German geologists were the first to take interest in these materials as a large part of the country is made up of this System. Alberdi (1864) was the first to formally described it and he named it Triassic because it is formed by three well differentiated units. The lower part, which rests almost horizontally over the Permian, is a formation of red conglomerates, sandstones and clays and he named it Buntsandstein (variegated sandstone). Over this there is an important carbonate formation with abundant marine fauna which he named the Muschelkalk (mollusc limestone). The upper unit is a series of clays, marls and sandstone coloured green, red or yellow and to which he named the Keuper. It contains important amounts of gypsum and in the uppermost levels limestone and dolomites. The German Triassic is very poor in fossils except in the Muschelkalk where they are principally local species which are not useful in the correlation with other areas. On the other hand the units of the German Triassic have no chronostratigraphic meaning. For example, the Buntsandstein in Germany corresponds to the Lower Triassic while in Luxembourg and a large part of Spain it corresponds not only to the Lower but also to the Middle Triassic (Virgili *et al*., 1977, 1987). For this reason when the Triassic was initially studied in the Alps (Bittner, 1896), where it is made up of extremely thick formations of fossiliferous limestone and dolomites, it was necessary to define a new stratigraphic nomenclature (Table 3). The Alpine stages were defined according to their biostratigraphic zones: ammonoids first and after fusulinids and conodonts.

After numerous meetings and discussions a proposal was agreed upon which was presented at the International Geological Congress held in Moscow in 1984, but it was not approved. There were disagreements with respect to the upper and lower limits. The problem with the upper part was related to the boundary with the Jurassic and the definition of the Rhaetian as the uppermost stage of the Triassic. However, the principal debate concerned the denomination of the Lower Triassic. Two names were proposed; the Scythian defined in the region of Scythes in the north of Crimea and the Werfenian defined in the Alpine region of Werfen near Salzburg. The second was ruled out as its limit with the Permian was not clear and furthermore was poor in fossils.

The most debated question was whether the Scythian should be divided into different stages. The geologists

Series	Stages
UPPER TRIASSIC	"RHAET" NORIAN
	KARUNIAN
MIDDLE TRIASSIC	LADINIAN
	ANISIAN
LOWER TRIASSIC	SCYTHIAN "WERFENIAN"

Table 3.- Initial stratigraphic nomenclature for the Triassic Period.
Tabla 3.- Nomenclatura estratigráfica inicial del Periodo Triásico.

working in the Himalaya and Russia considered that there should be two divisions and those working in Greenland and the Northern Rocky Mountains, four, because in these regions the series are much thicker and it is possible to distinguish many more distinct biozones (Table 4). It was a long discussion and finally at the International Geological Congress, held in Kyoto in 1991, an agreement was reached. The name of Scythian was accepted as synonymous with the Lower Triassic and was divided into two stages: the Induan, whose name was derived from the Indus river in the Himalaya, and Olenekian from the Olenek river in the south of Siberia. Four proposed names by the geologists working in the Rocky Mountains were also accepted as substages (Table 5).

2.3. The Permian-Triassic boundary

In order to tackle this task a special working group was created in 1981, the PTBWG (Permian Triassic Boundary Working Group), which started its work in the north-west of Canada and the Himalayas. In 1984 they proposed as the base of the Triassic the biozone of *Otoceras wodwardi*. Later, in 1986, the previously mentioned Chinese geologists who had proposed the Changhsingian as the upper stage of the Permian considered that it would be better that the reference biozone was *Hindeodus parvus* because this conodont was more abundant and widespread (Yang *et al*., 1984, 1987, 1995).

LOWER TRIASSIC	SCYTHIAN	Spathian	Olenekian
		Smithian	
		Dienerian	Induan
		Griesbachian	

Table 4.- The two stages of the Scythian accepted in the Geological Congress, held in Kyoto in 1991.
Tabla 4.- Los dos pisos del Scytiense aceptados en el Congreso Internacional de Kioto celebrado en 1991.

In a meeting of the PTBWG in Calgary, Canada in 1993 three proposals were put forward for the definition of the P/T boundary: Meishan in South-East China, The Guryul valley, in Kashmere, and Selong, in Tibet. After several years of meetings and discussions, finally in 2001 the International Commision of Stratigraphy adopted the Chinese proposal. The section of Meishan is not only the most accessible but also had the advantage that it corresponded to the region where the upper stage of the Permian (the Changhsingian) was defined (Fig. 1).

3. The rocks of the Permian and Lower Triassic

3.1. The study of the rocks

To explain the problem raised in the definition of an universally valid chronostatigraphic nomenclature for the Permian and the Triassic, reference has been made to the characteristics of the rocks deposited during these periods. However, to reconstruct the landscape of our planet throughout the 50 million years of this history we need to explain the geometry of these materials. In other words, to locate the deposits of these materials on the Earth's surface and also to analyse the geodynamic evolution of the basins where they were deposited.

Clearly, it is now impossible for us to do it in a complete and detailed way. Therefore, we will only consider in more detail the main features of the Iberian Peninsula and Western-Central Europe.

3.2. The Iberian Block

In Spain, the Permian was almost unknown 80 years ago (Patac 1920; Dalloni, 1913, 1938). The Triassic, on the other hand, has been the subject of numerous studies, but the age of the different lithologic levels was not clear and its limits with the Permian and with the Jurassic even less so. The term "Permotrias" was frequently used to name the red detritic sequences which make up the

Periods	Series	Stages	m/years	Substages
JURASSIC				
TRIASSIC	UPPER	RHAETIAN	199.6 ± 0.6 203.6 ± 1.5	
		NORIAN	216.5 ± 2.0	
		CARNIAN	228.0 ± 2.0	
	MIDDLE	LADINIAN	237.0 ± 2.0	
		ANISIAN	245.0 ± 1.5	
	LOWER "SCYTHIAN"	OLENEKIAN	249.7 ± 0.7	SPATHIAN
				SMITHIAN
		INDUAN	251.0 ± 0.4	DIENERIAN
				GRIESBACHIAN
PERMIAN				

Table 5.- The chronostratigraphic nomenclature of the Triassic Period proposed in the International Geological Congress of Kyoto in 1991. Four proposed names for the Lower Triassic by the geologists working in the Rocky Mountains were also accepted as substages.

Tabla 5.- Nomenclatura cronoestratigráfica para el Periodo Triásico propuesta en el Congreso Internacional de Kioto (1991). Se aceptaron también cuatro nombres de subpisos propuestos por geólogos que trabajaban en las Montañas Rocosas.

greater part of the Permian and the base of the Triassic. It was not until the end of the 1950's for the Triassic (Virgili, 1958) and the beginning of the 1970's for the Permian (Virgili *et al*., 1973, 1976; Sopeña *et al*., 1977), when there were valid models which helped us to understand the sedimentary evolution of these two periods. Today, the established models for the Iberian Peninsula have given us the key to decode this part of history for a large part of Western Europe.

From the end of the Paleozoic, the Iberian Peninsula constituted a small block of the Earth's crust, a microplate, located between the African and European plates. They were separated by some important tectonic lineations with a complex evolution. The results of these tensions were the faults and dislocations inside the Iberian Microplate which were especially mobile from the end of the Carboniferous until the beginning of the Triassic period (Arthaud and Matte, 1977; Arche and López-Gómez, 1996).

The "tardi-hercynian" movements in the Iberian Microplate formed numerous, and, in general, small depressions in which the sediments were accumulated (Fig. 2). The deposits are of very variable thickness (from a few metres to more than two thousand metres), always continental, usually red and detritic, as conglomerates, sandstones and clays. Sometimes, layers of gypsums and lacustrine limestones are interbedded. They are structured in different units separated by discontinuities which denote interruptions in the sedimentary process and sometimes by internal discordances which are the result of the tectonic movements suffered by the basins during sedimentation. Volcanic material in the form of ash and pyroclasts, and sometimes important deposits of basalt and andesite flows are very abundant, especially at lower levels. It is poor in fossils, despite having flora and abundant microflora which sometimes permits the correlation with the standard stages in the marine series. Recently, tetrapods footprints have begun to be studied, which will

	Stephanian-Autunian	**Autunian (1 and 2)**	**Thuringian**	**Anisian**	**Anisian-Ladinian**
A: **Pyrenees**	*Taeniopteris, Neuropteris, Neuropteroides, Lebachia, Ernestiodendron..*	*Odontopteris, Mixoneura, Cordiatites, Potoniesporites, Cordaitina sp., Gardenasporites, Costapollenites elipticus…*	*Falcisporites zapfei, Limitosporites parvus,Gardenasporites, Jugasporites, Lueckisporites parvus, L. virkkiae, Nuskoisporites dulhuntii Endosporites....*	*Triadispora staplini, T. Falcata, Illinites kosankei, Stellapollenites thiergartii..,*	
B: **Cantabrian Mountains**		1:*Callipteris conferta, Sphenopteris minutisecta, Pecopteris hemiteliaides, Annularia stellata,* 2:*Lebachia parvifolia, L. cf fallax, Taeniosporites, Neuropteris sp., Callipteris conferta*			
C: **Central System**		*Callipteris conferta, C. raimondii, Pecopteris denispei,,Odontopteris sp., Anullaria stellata, Vittatina costabilis, Sphenophyllum, Potonieisporites novicus…*			
D: **Western Iberian Ranges**		*Cyclogranisporites pergranulatus, Vittatina costabilis, Pytiosporites westfaliensis, Gardenasporites delicatus, Potoniesporites novicus...*	*Lueckisporites virkkiae, Nuskoisporites dulhuntyi, Falcisporites schaubergeri, Paravesicaspora splendens, Jugasporites delasaeuci....*		*Verrucosisporites remjanus, Hexaccites muelleri, Triadispora staplini, T. falcata, Allisporites cf. grauvogeli,...*
F: **Eastern Iberian Ranges**		*Callipteris conferta, Lebachia piniformis, Cathaysiopteris whitei, Equisetites elongates, Umbellaphyllites annularoides, Gigantonoclea largrelli*	*Lueckisporites virkkiae, Vesicaspora ovata,Limitisporites sp., Taeniaesporites albertae*	*Allisporites toralis, Triadispora staplini, T. Crassa, Voltziaesporites heteromorpha..*	
G: **Catalan Range**				*Lundbladispora sp., Cicadophytes sp., Triadispora crassa, Stellapollenites thiergarti, Voltziaesporites heteromorpha*	
H: **Balaeric Islands**			*Lueckisporites virkkiae, L.singhii Lunnatisporites cf. novialensis, Nuskoisporites dulhuntyi, Paravesicaspora splendens, Klausipollenites schaubergeri, Falcisporites stabilis, F. zapfei, Illinites unicus…*	*Porcellispora longdonensis, Sulcosaccispora minuta, Triadispora staplini, Alisporites grauvogeli*	

Table 6.- Main palynological associations of the Stephanian-Autunian, Autunian, Thuringian, Anisian and Anisian-Ladinian for the different Permian-Triassic basins of the Iberian Peninsula and Balearic Islands.

Table 6.- Principales asociaciones palinológicas del Estefaniense - Autuniense, Autuniense, Thuringiense, Anisíense y Anisíense-Ladiniense de diferentes cuencas permo-triásicas de la Península Ibérica e Islas Baleares.

undoubtedly permit more precise dating. The correlation is specially difficult as the small independent basins have very different sedimentary histories and for this reason, the materials deposited have diverse lithologic characteristics (Virgili, 1989; López-Gómez *et al*., 2002; Sopeña *et al*., 2004).

At the end of the Permian and throughout the lower Triassic, the tectonic mobility slowed and the sedimentation

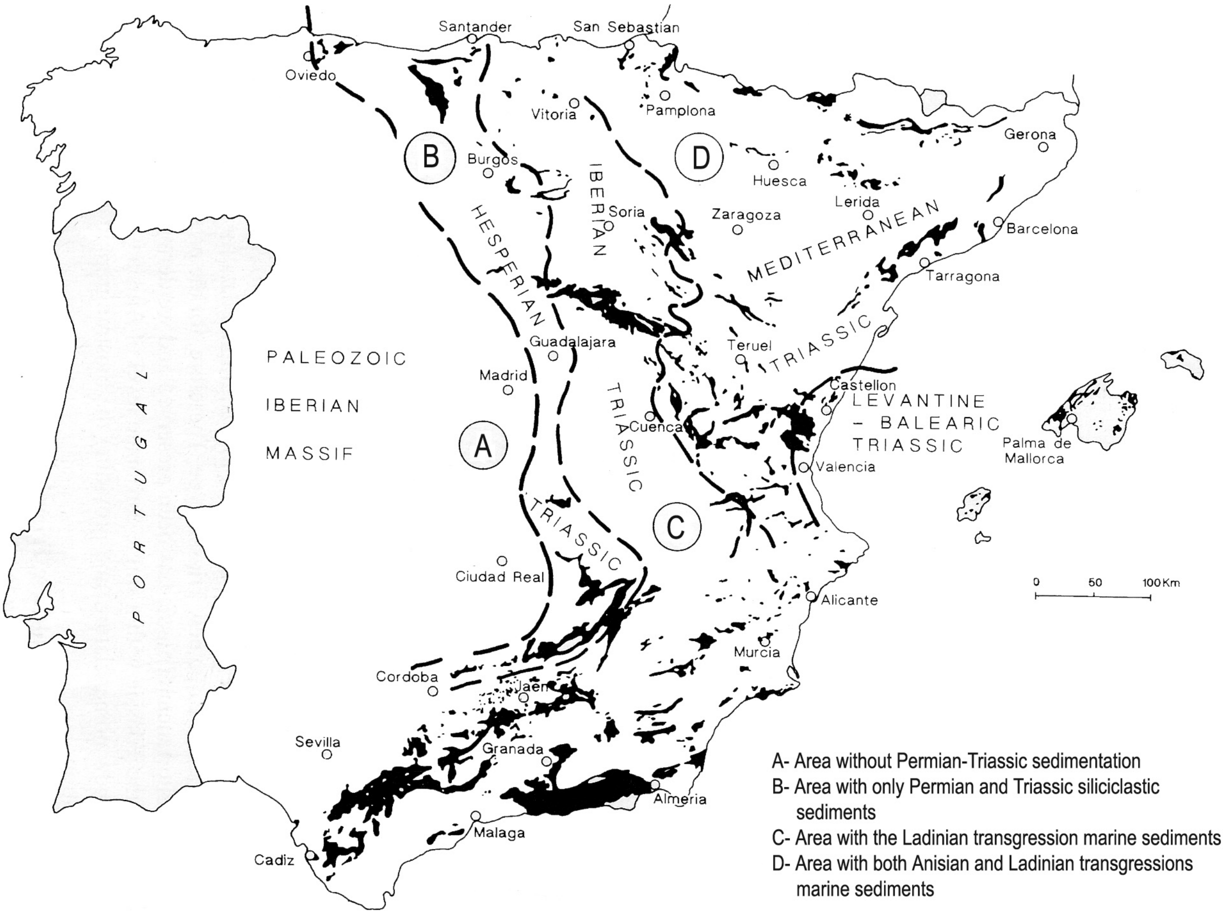

Fig. 2.- Permian-Triassic outcrops in Spain. Modified from López-Gómez *et al.* (1998). Reproduced with permission of the authors.
Fig. 2.- Afloramientos del Pérmico y Triásico en España. Modificado de López-Gómez *et al.* (1998). Reproducido con permiso de los autores

became more general; the Iberian Microplate became covered with vast alluvial plains where the sandstones and conglomerates of Buntsandstein characteristics were formed. During the Middle Triassic, a marine transgression advancing from the east, covered the eastern part of the Peninsula and deposited the Muschelkalk limestones, whose ages differ from one place to another (Fig. 2). At the extreme east, they began in the Anisian, and the central part in the upper Ladinian; the extreme western part did not become covered by sea waters and the detritic sedimentation continued throughout all of the Triassic. The sequence culminates in the Upper Triassic with variegated red and grey clays and marls with anhydrite, gypsum and sometimes sandstone. This unit is the Keuper, which just like the Muschelkalk and Buntsandstein, contains materials analogous to those deposited in a large part of Western Europe at the same time. The diagram shown in figure 3 represents a synthetic vision of the characteristics of the Permian and Early Triassic rocks in the Iberian Block. The vertical axis refers to time and, as such, bears no relation to the thickness of the sequences. The most characteristic points having dating based on palynological criteria have been selected for consideration, but clearly the information available at this moment is much more abundant than that which was possible to include here (Table 6) (López-Gómez *et al.*, 2002, 2006; Sopeña *et al.*, 2004; Virgili 1989, Virgili *et al.*, 2001).

The Pyrenees (Fig. 3A) is where Permian rocks have the most extensive outcrops and show greater tectonic deformation. The thickness varies between a few metres and two thousand metres (Gisbert, 1984; Lucas, 1995; Broutin *et al.*, 1988). They are composed of conglomerates, sandstones, shales and clays which are organised in different and sedimentary layers. Some layers contain plant remains which Dalloni (1930, 1938) identified as Permian. Volcanic rocks are very abundant in the form of basalts, andesites and pyroclasts (Lago *et al.*, 2004a). The base of the Permian almost always rests on black shale with some coal deposits containing Stephanian flora. It is impossible to identify the Carboniferous-Per-

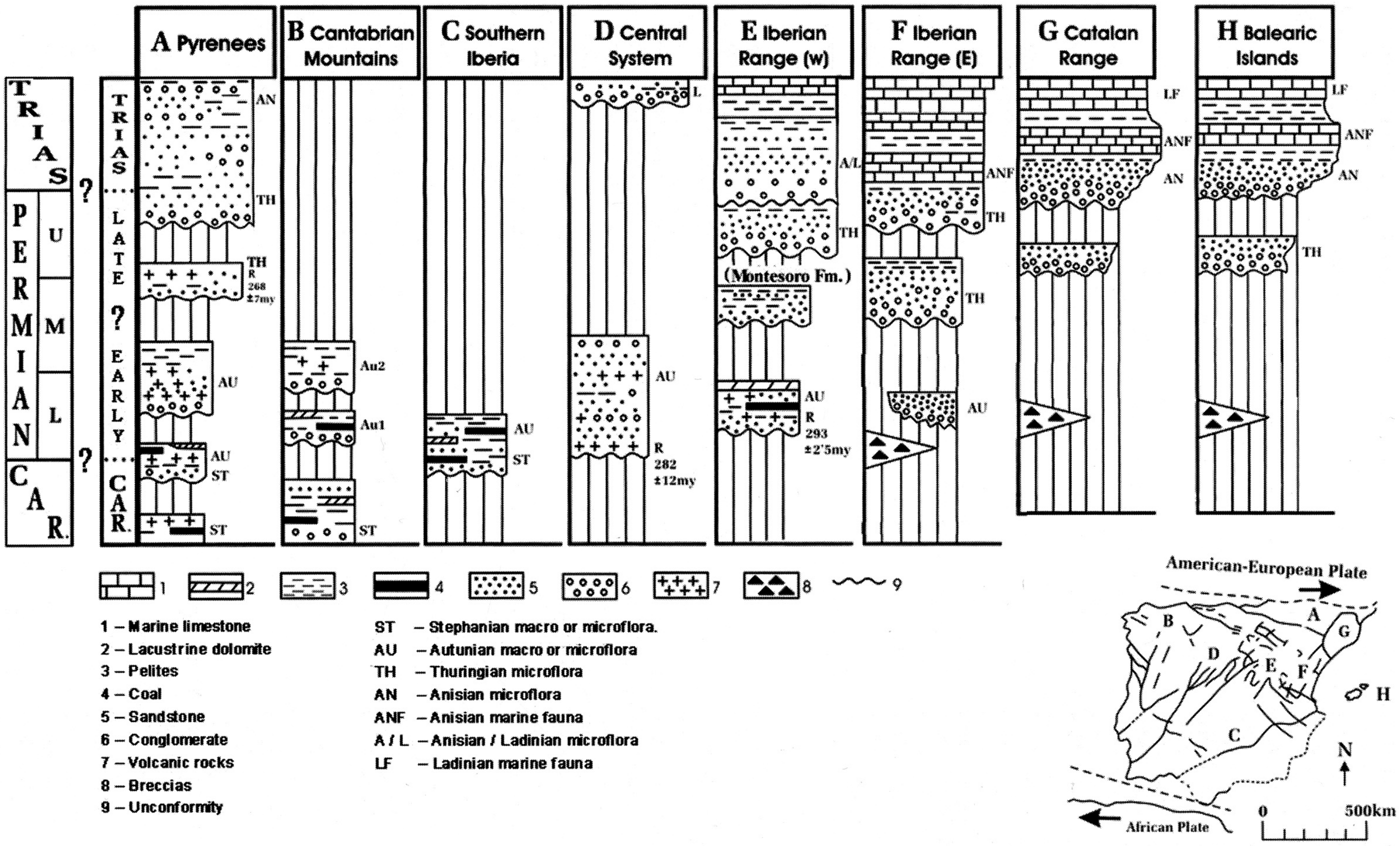

Fig. 3.- Stratigraphic sketch of the Upper Carboniferous, Permian and Lower-Middle Triassic from different areas of the Iberian Peninsula and Balearic Islands. After Virgili *et al.* (2005).

Fig. 3.- Esquema estratigráfico del Carbonífero Superior, Pérmico y Triásico Inferior-Medio de diferentes áreas de la Península Ibérica e Islas Baleares. Tomado de Virgili *et al.* (2005).

mian boundary, as in the first unit of the Permian base (made up of sandstones, grey clays with coal deposits, lacustrine limestone and volcanic rocks) upper Stephanian and Autunian floras are mixed. This confirms the supposition put forward in the previous chapter that these two flora do not have chronostratigraphic significance, but represent different climatic conditions and could have coexisted at the same time. The unit above it is analogous in composition, but red in colour and containing only Autunian microflora. Above, there is another similar unit, but the microflora is Thuringan, which is to say that they correspond to the Upper Permian. The dating of the volcanic rocks allows us to presume that the lower part of this unit may correspond to the Middle Permian (Lago *et al*., 2005), but this epoch has not been identified paleontologically anywhere in the Iberian Peninsula. On top of this sequence lies another unit which has the typical Buntsandstein characteristics of all Western Europe. Between these sequences there is an important unconformity which for a long time was thought to mark the limits between the Paleozoic and Mesozoic. But, as these materials have been shown to contain Thuringian microflora in the basal levels (Virgili *et al*., 1976, 1977) this unconformity must be intrapermian. An important difference between the Buntsandstein and the lower units, is that it hardly contains volcanic rocks and the conglomerates are only composed of quartz pebbles. Anisian microflora have been discovered in the upper levels of the Buntsandstein (Broutin *et al*., 1988) and as such, the Permian and Triassic present an apparent sedimentary continuity. It is necessary to point out that in neither the Pyrenees nor any other site the Iberian Peninsula have the Scythian stage well paleontologically characterised, which led some authors (Rosell *et al*., 1988) to believe that during this age, there was an interruption in the sedimentation. The sequence continues with the Muschelkalk and the Keuper with gypsum and ophites. Its complex tectonic structure makes it difficult to study its stratigraphy. At the west part of the Pyrenees, the Permian and the Triassic form complex outcrops which continue as far as the Basque Country and Cantabria, about which there is still little information.

In the central part of the Cantabrian Mountains, in Asturias (Fig. 3B), the Permian is totally different. As in the Pyrenees, it rests upon typical Stephanian sediments, but it is much thinner and is composed of two very different formations: the lower grey-black formation with layers of coal and the red upper one; both containing Autunian flora and volcanic rocks. In the east of Asturias, near Santander, there is a younger red formation, but its relationship with the two previous ones is not clear (Martínez García *et al*., 1994). The Mesozoic sedimentation begins after a long sedimentary interruption as the formation lying directly over the Permian, despite being of Keuper facies, has a Hettangian age.

There is also a set of outcrops in southern Iberia (Fig. 3C) which are difficult to intercorrelate. One of these, Guadalcanal, to the north of Seville (Broutin, 1977), shows that the Autunian and Stephanian flora coexisted in time. Some grey-black detritic material in which alternating layers containing Autunian and Stephanian flora have been found in a disused coal mine. This fact could be explained by alternating humid and dry climatic periods.

Numerous faults were produced in the Central System (Fig. 3D) at the end of the Carboniferous or the beginning of the Permian. Tectonic depressions, which contain thick sediments with diverse characteristics were formed: sometimes sandstones and polygenic conglomerates of a red colour and, in other occasions, huge outcrops of volcanic rocks (Hernando *et al*., 1980). Using radiometric and paleontological dating techniques it was proved that they only represented the Lower Permian (Lago *et al*., 2004a, b). The Upper Permian was either not deposited or was later eroded. Directly above, lying on an important, unconformity there are red detritic materials from the Middle Triassic (Ladinian).

The Permian and Triassic of the eastern side of the Iberian Block are much more important (Fig. 3 E, F,G). There were some small isolated basins at the beginning of the Permian, shortly after the sedimentation was generalised and thick layers of red sandstone and conglomerates with quartz pebbles completely covered the eastern half of the Peninsula, with the exception of some higher reliefs which form the boundary of three well-characterised basins (Arche *et al*., 1996, 2004) (Fig. 4).

There is a western basin whose materials forms the Castilian branch of the Iberian Range and a second basin which, in part, corresponds to the Aragonese branch and the rest is presently covered by Tertiary materials from the Ebro depression. Finally, the third most easterly one, which constitutes the Catalan Range, and continues

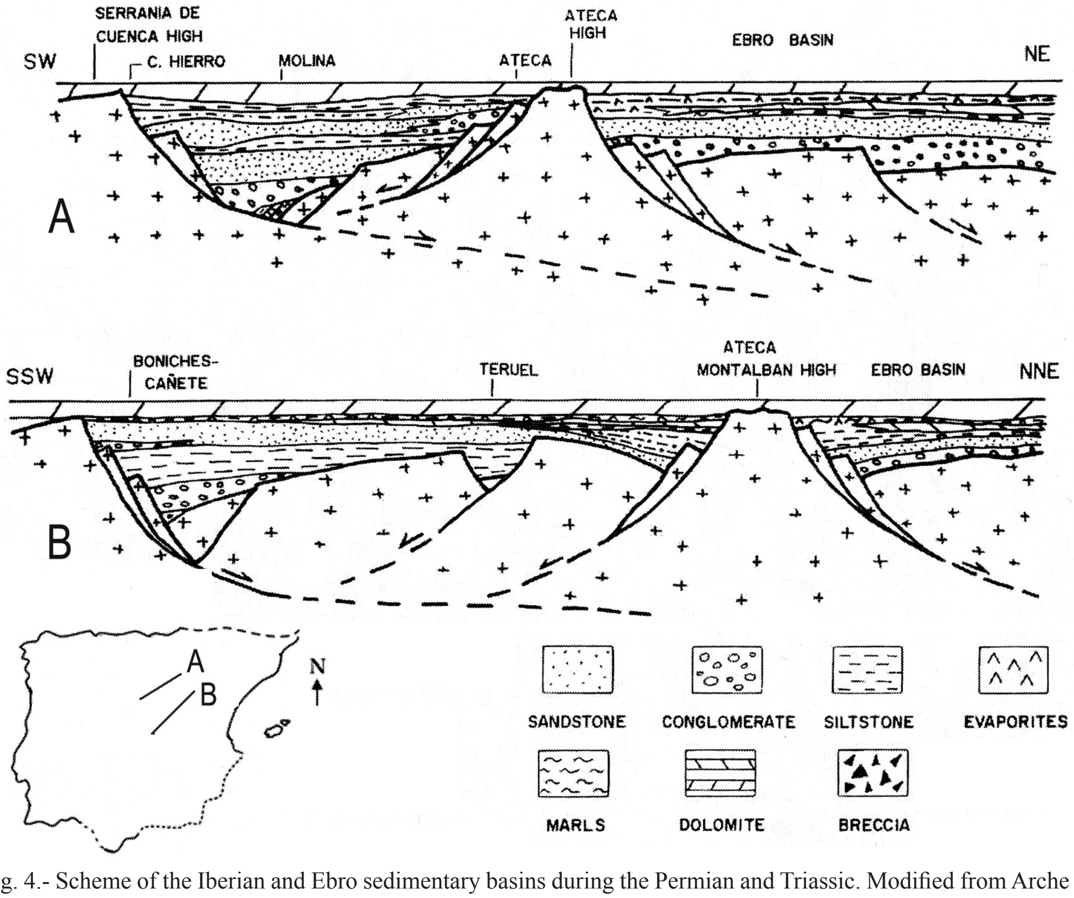

Fig. 4.- Scheme of the Iberian and Ebro sedimentary basins during the Permian and Triassic. Modified from Arche and López-Gómez (1996).

Fig. 4.- Esquema de las cuencas sedimentarias Ibérica y Ebro durante el Pérmico y el Triásico. Modificado de Arche y López-Gómez (1996).

beneath the present Mediterranean waters. The western and central basins were separated by the Ateca high and the central part of the eastern one by the Lleida high. It should be noted that the adjoining diagram represents the deposition of the materials at the end of the Triassic, that is, long before the alpine orogeny (Fig. 4).

At the end of the Carboniferous and beginning of the Permian, in the most western sector (Fig. 3 E) there were small basins where a mixture of volcanic rocks, conglomerates and sandstones with intercalations of black shales containing plant remains were deposited. The flora corresponds to the Autunian and in some cases to the upper Stephanian. The sedimentation subsequently overflowed these basins and spread widely. Conglomerates and red sandstones were deposited; this typical Buntsandstein constitutes the present-day dominant landscape of the Iberian Ranges and is known by the name of “Rodeno”. The basal levels contain Thuringian flora (Ramos, 1979), at higher levels the microflora is Anisian or Ladinian. As in the case of the Pyrenees, neither it is possible here to define the boundary between the Triassic and the Permian. Covering this group there is a series of red clays and marls and finally limestones and dolomites which correspond to the Ladinian (Doubinger *et al.*, 1977; Díez *et al.*, 1996). The Muschelkalk represents the marine transgression of the Middle Triassic, when the waters of the Tethys covered the eastern part of the Iberian Block (Fig. 2). The Triassic culminates with variegated marls with gypsum that constitutes the Keuper, whose characteristics are uniform in all the Peninsula and the greater part of Central and Western Europe.

It is worth highlighting the division of the Permian in two great tectono-sedimentary cycles. The first, is related with the Upper Carboniferous while the second extends into the Triassic. This fact is a constant in the east of the Iberian Peninsula and also in a large part of Western Europe. These two cycles do not have any chronostratographic significance, even though the lower cycle corresponds in part to the Early Permian and the higher to the Late Permian. The discontinuity which separates the two cycles represents wholly or partially the Middle Permian. It should be remembered once again, that the lithologic or tectonic limits never correspond exactly to isochronic lines.

The materials which crop out in the Aragonese branch (Fig. 3F) of the Iberian Ranges were deposited in the central sector of the basin. The Permian series are not very different from those described in the Castilian branch, but they offer more precise chronostratigrafical data (Riba, 1959). The lower levels contain very rich Autunian flora, similar to those from the Pyrenees and Cantabrian Mountains. At higher levels, Thuringian microflora can be found. The Buntsandstein also presents Thuringian flora at the base and, in the higher levels, Anisian and Ladinian flora, which makes it impossible to mark the limit between the Permian and the Triassic. The most important difference between the Aragonese and Castilian branches corresponds to the Triassic series. In the western part of the Iberian Range the detritic deposits are more abundant and the Lower and Middle Triassic show Buntsandstein facies. The sediments of marine carbonates are restricted to the upper Ladinian. In the eastern part, the Middle Triassic has two carbonatic layers: the lower Muschelkalk (Anisian) and the upper Muschelkalk (Ladinian), separated by an “Intermediate Red Layer” of red variegated clays with sandstones and gypsum.

Further to the east rise the Catalan Coastal Ranges, where Triassic rocks appears again with similar characteristics to those described previously, but under more favourable conditions for study. Even to this day, the Prades Sierra, in the Catalan Ranges, continues as the reference location to understand the Triassic, not only in Catalonia, but in all Western Europe (Fig. 3 G). Recent studies by teams from the University of Barcelona have permitted a reconstruction of the environments and the biocenosis of the marine platform and the coral reefs where the limestones and dolomites of the cliffs of the Prades area were formed (Calvet *et al.*, 1995). The identification of Permian rocks has caused, however, more difficulties. There are not any paleontological data, but the most recent studies (Arche *et al.*, 2002, 2004) have discovered sufficient lithologic criteria to assure that, in some sites, the base of the Buntsandstein corresponds to the Permian. The oil exploration done in the continental platform of the Mediterranean, off-shore from Tarragona, have permitted us to prove that the Triassic is very similar to that in the south of the Catalan Coastal Range, even though the carbonate sedimentation becomes more important towards the east.

In the Balearic Islands both the Permian and the Triassic reappear. On the island of Menorca (Fig. 3H), the less complex tectonic structures allow us to establish analogous series to that in the south of Catalonia, although in the islands the Permian is better characterised by a rich Thuringian microflora (Arche *et al.*, 2002; Ramos and Doubinger, 1989).

The Betic Ranges are not taken into consideration here because they have a different story, both figuratively and in the true meaning of the word. The Permian and Triassic rocks which constitute a large part of them, seem to have been deposited in an indeterminate place in the western Mediterranean, far from their present-day location. They were refolded and structured during the Alpine orogeny, almost at the same time as the Pyrenees, but they were not incorporated into the Iberian Peninsula until the end of the Tertiary period, 30 million years ago. Their tectonic structure is very complex and is still subject to debate, and this makes it difficult to establish the stratigraphic series and even more so to reconstruct their paleogeographic evolution.

3.3. Western and Central Europe

On the other side of the Pyrenees, in the South of France, between Provence and the Central Massif, the Permian has some similar characteristics to those of the Iberian Peninsula (Châteauneuf *et al*., 1989). Several tectonic basins contain conglomerates, sandstones and clays with layers of black shale and coal, almost always with floral remains. Volcanic rocks are present, but with the exception of the Esterel Massif, they are much less abundant than in the Pyrenees. One of the most studied outcrops is the coal mine located in the proximity of the city of Autun, which was used to define Autunian. It displays an abundant and well-studied flora (Broutin *et al*., 1999) considered representative of the Lower Permian and has been identified in many other sites around the world. The problem is that it is neither possible to establish its lower boundary, related with the Carboniferous, nor its upper boundary, related with the Triassic. The problems concerning the use of this term as a chronostratigraphic unit have already been discussed. In recent studies (Gand *et al*., 2000), results of analysis of the footprints of tetrapods allows the correlation of these series to those of central Europe. As in the Iberian Peninsula, there is a Buntsandstein facies lying unconformably and onlaping over these rocks. Again, it is impossible to recognise the limit between the Permian and Triassic, as it do not correspond with the unconformity and there are not enough paleontological data.

The marine influence and carbonatic sedimentation increases towards the east. The Triassic of Jura has similar characteristics to those of the Prades Sierra, in the Catalonian Ranges. Still farther, towards the south-east, in the Alps, the characteristics are completely different, but will be analysed in the next section. In Provence and Côte d'Azur, from Toulon to Montecarlo, the Permian materials are very similar to those in the Pyrenees (Virgili *et al*., 2001, 2006).

Germany is the European country where the Permian and the Triassic are best represented and studied (Falke, 1972). As was previously mentioned, it is where Alberdi (1864) defined the Triassic and gave it its name (three-tria) for being composed of three levels: Buntsandstein, Muschelkalk and Keuper. This series has served as the reference for this period across the greater part of Central and Western Europe (Germanic Trias). The Permian is also well represented here and forms the landscape of a good part of east Germany and Poland. There are also the red, detritric series with volcanic material, as in Spain and France, but the lithostratigraphic characteristics and the geometry of the sedimentary basins are so different that it is not possible to establish a correlation with these areas. Here also two great tectono-sedimentary cycles can be distinguished: the Rotliegendes at the base and the Zechstein in the upper part, separated by a large sedimentary interruption and an unconformity. It is clear that the base of the Rotliegendes corresponds to the Lower Permian, and the upper part probably to the Middle. The Zechstein, in spite of its considerable thickness, almost certainly represents a very small part of the Upper Permian. The duration of the sedimentary gap separating both formations is unknown. The Permian sedimentation begins in well-individualised depressions filled up with red detritic materials with numerous hiatus and internal unconformities, a testimony to the synsedimentary tectonic activity of the faults defining them. Little by little, the sedimentation became slower and the subsided areas were filled, but at some time during the Middle or Upper Permian, important changes occurred. After a pronounced sedimentary interruption, the Zechstein marine sediments were deposited, whose characteristics were explained in the previous chapter. It represents a marine transgression from cold shallow waters, coming from the north-west out of the Boreal Sea (Schneider *et al*., 1994).

These Permian formations of Central Europe continue west as far as the Netherlands and the North Sea. They do not appear on the surface, because they are covered by more recent materials and sea water, but are well known thanks to the numerous borings done to exploit the oil and gas they contain. Recently, the formations from which oil is extracted, have been filled with the CO_2 produced by industrial activity in order not to release it into the atmosphere. The *New Red Sandstone* and *Magnesian Limestone* represent the Permian and Triassic in the British Isles, which are the most western deposits of these materials in Europe. The Magnesian Limestone represents a marine transgression which continues to Central Europe with the Zechstein.

3.4. Meridional Europe: The Alpine axis

There is an irregular string of ranges across the south of Europe, from the Pyrenees and Betics to the Alps, the Carpathians, the Balkans, the Dinarides and the Taurides, and across Turkey linking up with the Caucasus and beyond, inside Asia and towards the Himalayas. Clearly, these ranges have a very different composition and tectonic structure, but the characteristics of the Triassic and Permian present strong analogies. In all of these, the sequences are composed primarily of carbonate rocks of marine origin while detritic levels are scarce or completely absent. They are the materials that form the majestic reliefs of the Dolomites and the Briançons. Despite having a very complicated structure and difficult access, their abundance in fossils and the excellent physical fitness of the geologists who have worked there, allows us to know well their stratigraphy. It is the so-called *Alpine Trias,* which allows us to establish the first chronostratigraphic scale for this period.

In the Permian sediments of Northern Italy, the transition between areas where continental deposits and marine deposits predominate can be observed (Cassinis *et al*., 1995). The research was much more difficult than in Central or Northern Europe because the south of Europe has been deeply deformed by the Alpine orogeny. Just as in the Iberian Microplate, two tectono-sedimentary cycles can be distinguished. The lower is a complex detritic deposit in small tectonic depressions active during sedimentation. They contain abundant volcanic rocks. The red colour predominates, but there are layers of black and grey clays, which contain abundant flora. The radiometric and paleontological data indicate that they correspond to the Upper Carboniferous and to the Lower Permian. The presence of the Middle Permian cannot be rejected, but still it has not been identified paleontologically. The characteristics of the upper cycle give a special personality to these sequences, which widely spill over to the previous sedimentary basins and is separate from the lower cycle by a complex unconformity. It is difficult to evaluate the duration of the sedimentary interruption (Cassinis *et al*., 1995). This higher cycle of the Permian in northern Italy is formed by an important detritic accumulation, the Verrucano, which has a certain analogy to the Buntsandstein. More to the south-east, this upper cycle is composed of shallow marine deposits, the Bellerophon Limestones. This marine formation, which crowns the Permian here, is totally different from that described before in Germany. The Zechstein was deposited in cold, relatively calm seawater, which invaded the European block coming from the northwest. On the other hand, the Bellerophon Limestones were formed in much warmer waters coming from the east, the Tethys, and announced an important marine transgression in which the carbonatic series forming the Alpine Trias would be sedimented. In the mountain ranges of the far east of Europe, the Taurid mountains in Turkey and the Caucasus in the south of Russia, the marine invasion began already in the Permian, and the whole sequence is formed by marine carbonates.

3.5. Other sites in the world: The marine basins and emerged blocks.

The characteristics described for the Permian and Triassic of the eastern European ranges is valid for the ranges that stretch as far as south Asia, and extend as far as the Pacific Ocean to eastern Siberia and the Rocky Mountains in Canada and north USA. With the logical differences between these sites, the Triassic and Permian complex is formed of thick sequences of fossil-rich limestones and dolomites, where there is almost always a continuity of marine sedimentation throughout these two periods. For this reason, they would offer the best sites to establish the chronostratigraphic series if it were not for their complex tectonic structure and difficult access, both for their complex orography and the often complicated socio-political situation.

As we have seen in the Iberian Microplate, the marine sedimentary basins were surrounded and limited by emerging blocks. These blocks were subjected to erosion and the majority of the resulting sediments filled the marine basins, although certain amount accumulated in the interior of the continents transported by rivers or by the action of wind. Evidently, in such an immense area as the Pangea the sedimentation was very varied as will be analysed in the following section.

4. The Earth's landscape at the end of the Paleozoic

4.1. A different planet

If astronauts were to observe our planet 290 million years ago, that is to say at the beginning of the Permian, they would have seen a very different world from today. An immense continent stretched from pole to pole occupying almost half of the Earth's surface, and a huge ocean occupied the other half, the Panthalassa. We call this super continent Pangea and was formed throughout the Carboniferous period by the regrouping of almost all the continental blocks that existed on the Earth surface. This reorganisation of the Earth's crust had its origins in a complex dynamic which was produced at the end of the Paleozoic: the Hercynian orogeny, which not only affected the structure of the crust, but also the deepest areas of the Earth and gave rise to volcanic, metamorphic and granitization processes.

This dissymmetry of the two hemispheres, on one side ocean and the other land, made the immense continental block of Pangea unstable due to the forces resulting from the rotational movement of the Earth. As a result, as the tensions generated by the tectonic movements increased, Pangea began to tear and break up and later, the different blocks began to disperse across the Earth's surface re-establishing a new equilibrium (Stampfli *et al*., 2001, 2002). We could say very schematically that a long and complex north-south crack began to open throughout the Mesozoic and Cenozoic and continued to open further giving rise to the Atlantic Ocean. At the same time, the American blocks were displaced to the west while Africa and Eurasia moved to the east until they arrived at their present geographical position. The Pacific Ocean is all that is left of the ancient Panthalassa, whilst the Atlantic is a "younger" ocean which has developed over the last 200 or 225 million years. Figure 5 shows the arrangement of Pangea 250 million years ago.

Paleomagnetism and information from the ocean beds have been the keys allowing us to decode the arrangement of the seas and lands during the previous geological eras (Wilson 1963, 1976; Coode, 1965; Dietz, 1961; Heezen, 1960; Irwin, 1959), something that had been incomprehensible for geologists for many years (Wegener, 1922). Cosmology and astronomy also give us information about the Earth during the Permian. The Earth's rotational velocity is slowly but constantly decreasing, and as such, the Earth rotated faster in the distant past. That is to say that 250 million years ago, the days and nights were shorter and a year also probably had a different duration. Furthermore, the axis of rotation, being more perpendicular to the ecliptic, made the seasonal climatic variations more pronounced, and the climatic zones were more marked, as the solar rays were perpendicular in the equatorial band throughout the whole year and always low at the polar caps. These factors evidently had an influence on the climate of the Earth. Another difference from our present world is that the Moon was possibly closer to the Earth and, as such, its action on the seawaters must have been more energetic, that is to say the tides were stronger and penetrated the continent further. As the days were shorter, the tides were not only stronger, but also more frequent and as such, the coastline dynamic was more active. Therefore, the atmospheric circulation was very different from today. The difference in temperature between the equatorial zones and the poles was very pronounced and as a result, the pressure gradient between the two areas was very elevated and must have produced very strong winds. The concentration of all the emerged lands in one continental block made the aridity of its interior much more acute than can be observed in present day deserts. Therefore, as a whole, our planet not only had a very different appearance from today, but also suffered more intense geological processes (Woods, 2005).

4.2. The two immense oceans: Panthalassa and Tethys

Not a lot is known about the great ocean which covered more than half of the planet. Its central and widest part continues to be submerged beneath the present Pacific Ocean or has been eliminated by subduction. The wide continental platforms were brimming with life and extensive carbonatic formations were sedimented. The best known part is the platform located at the NW edge of the Pangea, where the sediments forming the Rocky Mountains in northern USA, Canada and also Greenland were deposited. They had cold waters with very abundant fauna and the sedimentation was almost continuous and calm throughout all the Permian and Triassic. Clearly, it would have been the ideal place to establish a good chronostratigraphic scale, but unfortunately studies were not started here until the bases of the subdivisions and the nomenclature for this period had already been established in Europe.

To the east of Pangea, practically following the equator, there was an enormous bay, a wide sea in reality,which opened to the Great Ocean in the east and towards the west arrived to the South of Italy and Tunisia. This sea, which has been given the name Tethys, could be considered to be the ancestor of our Mediterranean, although it has become considerably reduced in size. The carbonatic sediments, which were deposited in its interior, make up the Permian in the eastern Alps, the Carpathians, the Balkans, the Urals and the Himalayas. Throughout the Permian and the Mesozoic it was an active tectonic area. The mobility was especially marked from the Cretaceous onwards when the sediments were refolded to produce the alpine ranges but before that, there had been a series of deformations (Figs. 5) which allowed the differentiation between the so-called Paleotethys, and the Neotethys. The Paleotethys already existed in the Carboniferous and was closed throughout the Triassic while the Neotethys gained importance throughout the Mesozoic (Gaetani *et al*., 2003; Deroin *et al*., 2003). Without going into more detail about the tectonic evolution, it is important to highlight the consequences this fact had in the problems there were in establishing the chronostratigraphy of the Permian. As described in the previous section, the definition of the different units first occurred in the Urals, where this tectonic mobility altered the marine sedimentary formations of the Middle and Upper Permian.

The higher stratotypes of the Permian were defined in Southern China, which corresponds to the centre of the Tethys. Here the marine sedimentation is almost continuous, disturbed only in the Middle Permian by the mobility of the Tethys. For this reason it was finally nec-

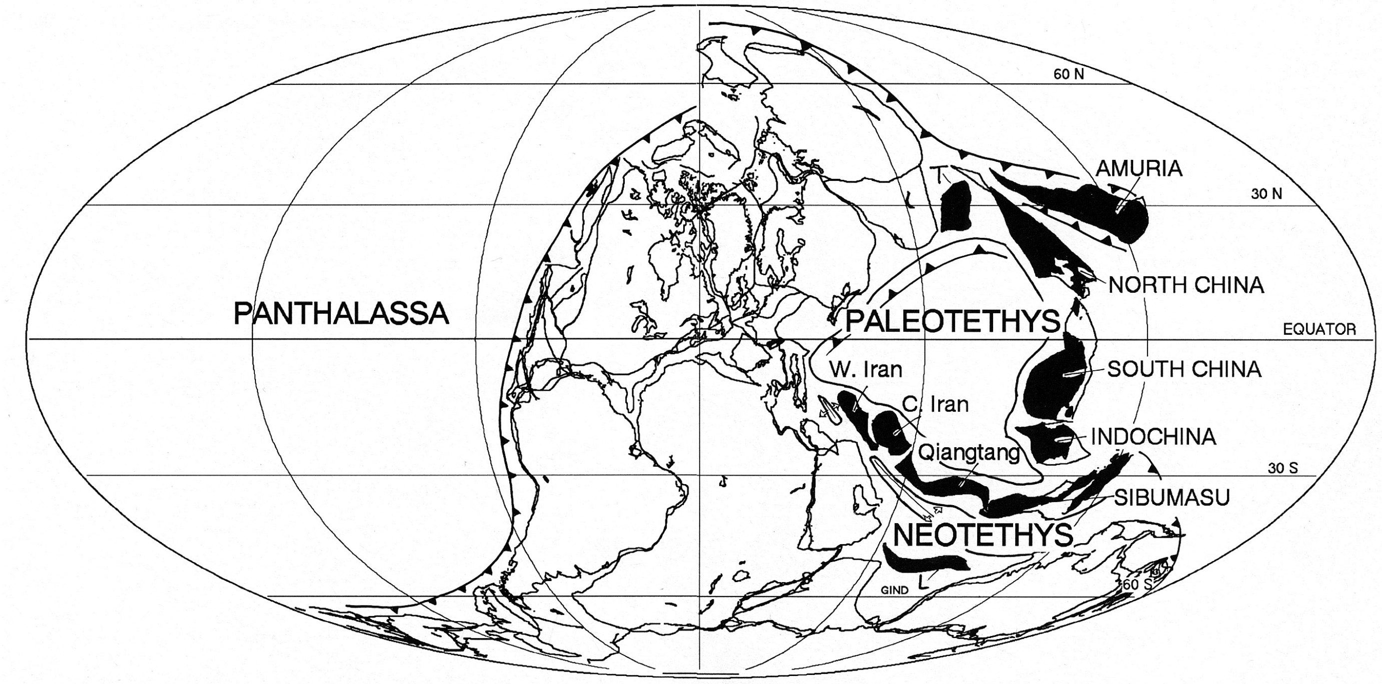

Fig. 5.- Paleoplate tectonic reconstruction and paleogeography for the Early Permian. The Asian terranes of the Tethys are labelled and the Iberian Peninsula is in black. Symbols (below in the figure): L- Lhasa block, GIND- Greater India. After Scotese and Langford (1995), reproduced with permission.

Fig. 5.- Reconstrucción tectónica y paleogeográfica continental global para el comienzo del Pérmico. Se destacan las zonas principales asiáticas del Tethys y la Península Ibérica está en negro. Símbolos (en la parte inferior de la figura): L- Lhasa Block, GIND- Greater India. Según Scotese y Langford (1995), reproducido con permiso.

essary to complete the series by defining the stages of the mid-Permian in the western platform of Panthalassa, in the Rocky Mountains and Texas. The problem was to correlate the "tethysian" and the "boreal" sequences to the north of Panthalassa. Clearly, the characteristics of the fauna were conditioned by the conditions of the waters, especially temperature and exposure to sunlight, with great differences between the Tethys, located on the equator, and the northern part of Panthalassa, located in the boreal zone (Fig. 5). There are common forms in both areas which enable us to establish correlations which finally permitted the approval of a definitive chronostratigraphic scale for the Permian at the International Geological Congress in 2004 (Florence, Italy), although there are still many problems to resolve. Especially complicated is the case of the continental series. In those areas which were under the tectonic influence of the mobility of the evolving Tethys during the Middle Permian (e.g Spain, France or Italy), these series are organised into two distinct tectonosedimentary cycles: a lower cycle, which has a certain continuity with the Carboniferous and a higher one linked to the Triassic (Virgili *et al.*, 2001; Virgili, 2006).

4.3. The Pangea Supercontinent

It is not easy to describe the landscape of this immense continent in a few words and even less so to give a valid combined vision for the fifty million years defined by the Permian. It is a period during which a gradual but dramatic transformation of the planet was produced. From a planet largely covered by luxuriant vegetation in the Carboniferous period it evolved to a dry and desolate world in the early Triassic. At the beginning of the Permian the vegetation was even more abundant which explains why the materials of this age in some sites contain large coal deposits and almost everywhere there are frequent black shales rich in organic material (Autunian).

The landscape in the Pangea was not uniform as it was composed of very diverse climatic regions, from the North to the South Poles. The two polar caps were also different (Fig. 6). The North Pole remained above the waters of the Panthalassa and the ice mass was small, but it was maintained throughout the Permian. On the other hand, the ice cap of the southern hemisphere was much larger and covered the lands which today form Antarctica, Australia, part of South America and central and south

Africa, but was soon transformed into a plain with great lakes. These immense ice mass deposited huge amounts of morrenic materials which are found today in the form of tillites (Scotese *et al*., 1995).

The Hercynian Orogeny at the end of the Carboniferous had formed large mountain reliefs. A mountain range stretched from the present day Appalachians to the Iberian microplate and across all of Europe in the northern hemisphere. Next to the western Pangea there was also a tectonically active area with important volcanic and magmatic manifestations. Although the most intense movements occurred in the Carboniferous, the relief continued to rise throughout the Permian producing tectonic depressions between the reliefs. Here, the sedimentation was especially intense and the alluvial and torrential deposits accumulated forming the detritic formations which are so abundant in the continental series of the early Permian. These tectonic movements deformed the materials, which were being deposited and were responsible for the unconformities and disconformities, which we see today inside these series.

The intense internal activity of the planet was also manifested in increased volcanism. Lava flows and volcanic ashes were mixed and intercalated between the detritic sediments. In some places, such as Siberia, they formed immense extensions of plateaubasalts reaching a thickness of two thousand metres and an extension of four or five times the present day Iberian Peninsula. The increased volume and the frequency of the volcanic emissions is one of the main characteristics of the Permian and this intensity has not occurred again in the history of the planet.

In the interior of Pangea, far from all marine influence, the environment was very arid, the vegetation very scarce and the vast alluvial plains slowly accumulated the detritic materials transported by ephemeral, slow-flowing rivers. There were great deserts with dune fields and endoreic lagoons, similar to the present day Algerian "chots", but much greater in size. At the coastlines, the tidal action and the waves collected and redistributed this material forming beaches, which alternated with saline lagoons. It was a landscape characterised above all by its monotony and extraordinary aridity. The uniformity of the majority of this immense continent explains why the materials formed in very distant regions at the end of the Permian and the beginning of the Triassic have such a similar appearance around the world. The Buntsandstein facies of Spain are not only identical to those of Strasbourg and Heidelberg, in Central Europe, but also to those of the Blue Mountains near Sydney (Australia) and the plains in Mongolia in the extreme NW of China. This is a situation which never occurred again in the history of the Earth.

These materials contain few fossils. This is not only because plant and animal life was very scarce on the continents, but because conditions for the conservation of remains were very unfavourable, as now happens on beaches and alluvial plains where most of the plant and animal fragments are destroyed before they can be fossilized. Despite this, plant fragments and mainly spores and pollen grains have been preserved, as they were more resistant. In addition there are insects and crustaceans, bones and spines, shells and animal footprints. Therefore, we know that the flora and fauna of that time which, although not very abundant, was very varied and contained the majority of the species which had existed during the Paleozoic era.

Clearly, the fauna and specially the flora, were greatly conditioned by the environment where they lived. The flora, which is more abundant and well studied, allows us to define three floristic provinces. In the southern hemisphere, the province of Gondwana (South America and Africa) is characterised by highly varied flora due to the differences in climate (from temperate to glacial). The northern hemisphere, Laurasia, is characterised by very poor flora from a dry temperate climate. In the Cathaysia province, corresponding to the tropical and equatorial regions at the shores of the Tethys, the flora was richer and

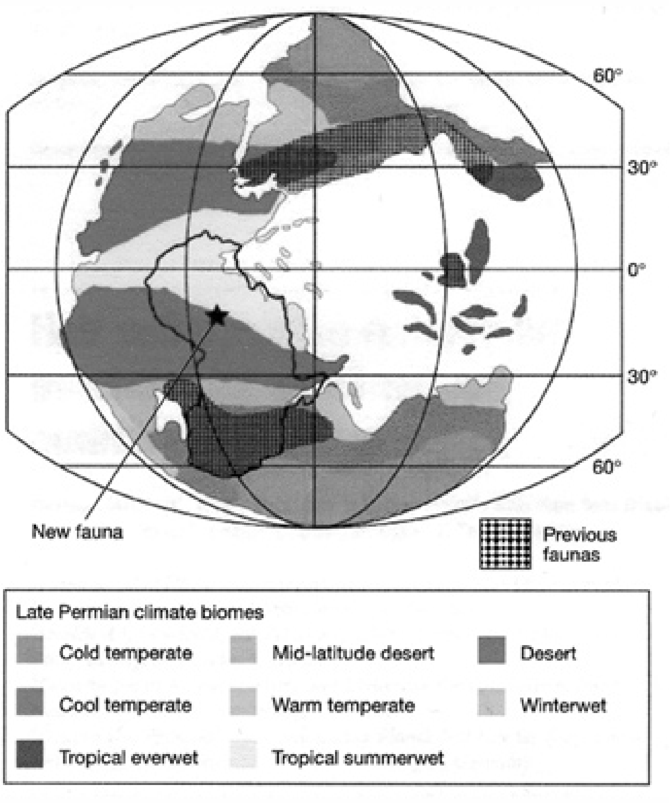

Fig. 6.- Tetrapods and climatic areas during the Permian. From Sidor *et al*. (2005). Reproduced with permission.

Fig. 6.- Tetrápodos y áreas climáticas durante el Pérmico. Obtenido de Sidor *et al*. (2005). Reproducido con permiso.

more abundant, and because of its climate and humidity it provided a refuge for the Carboniferous flora. During the Permian, many characteristic species of the Westphalian survived in this province having become extinct in the other provinces. The continental blocks, which later gave rise to Australia and New Zealand, were separated from Pangea at this time and, it is the reason why some tree ferns still grow there at the present day and are true living fossils from the Carboniferous. In the Iberian Peninsula forms from Gondwana and Laurasia and also some from Cathaysia cohabited during the Permian.

The limit between the continent and the sea continued changing and at times the waters covered the emerged lands and became shallow seas. At the end of the Permian, the waters from the Boreal Ocean covered part of Canada and advanced over what is now north and central Europe (the North Sea, the Netherlands, Germany and Poland). The Zechstein was deposited here and when the huge bay became disconnected from the open sea and evaporation was stronger, the saline deposits of Central Europe were formed.

4.4. The start of the Mesozoic era

With the start of the Mesozoic era, the world began to arrange itself as we can see it today. The 250 million years that have passed since then is only a small part of the planet's history, representing approximately only 5% of the total age of the Earth, but it is the chapter we know best. Its description occupies the majority of the pages of the geological history textbooks and this disguises the reality. Only the beginning of the history would have been analysed on their previous pages, from the final Hercynian cycle to the beginning of the Alpine cycle. This last cycle culminated in the formation of the long string of mountain ranges that go from southern Europe through the Himalayan regions and stretching as far as the Pacific region. At this time two processes began which directly affected the Iberian Peninsula: the opening of the Atlantic and the complex evolution of the Tethys. The Iberian microplate rests between two big blocks: the Laurasian plate, to the north, and Gondwana, to the south (Stampfli *et al.*, 2001) and under the influence of two important active structural lines.

5. The Great Crisis

5.1. The extinction of living species

Everybody knows today that currently extinct species of animals lived in the past, and some of these are better known and even more popular than some living beings. The current "passion" for dinosaurs is a good example of this. But in fact, the conscious hunt for the reality and significance of these disappeared worlds did not begin until the end of the 18th century.

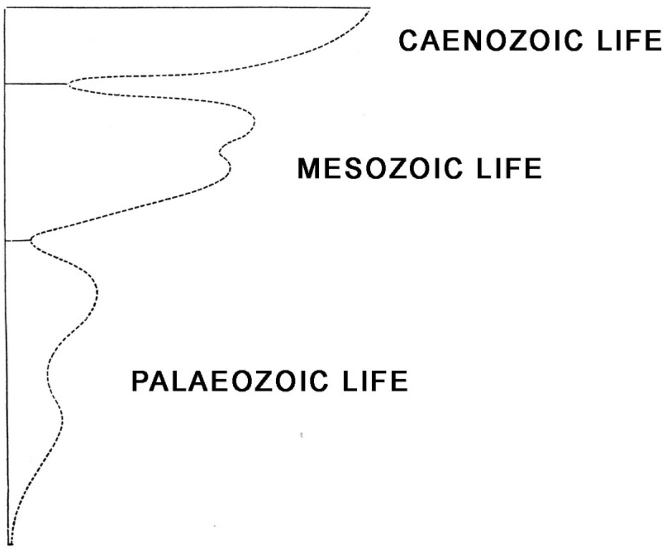

Fig. 7.- John Phillips´s curve (1860) showing diversity through time. Its general shape remains accepted today.

Fig. 7.- Curva de diversidad de John Phillips (1860) a lo largo del tiempo geológico. Su tendencia general se mantiene hoy todavía vigente.

The drastic changes in the paleobiological diversity of the fossils throughout time were recognised in the 19th century, permitting us to distinguish three great stages in the Earth's history. In 1840 J. Phillips proposed the names Palaeozoic (1840), Mesozoic (1818) and Cenozoic (1840), or "ancient", "intermediate" and "recent fauna" for these three divisions of history (Fig. 7). Clearly this meant that at the limits between one another, a new species had appeared, a fact which was attributed to "successive creations", and those which had disappeared, to the fact that a series of archaic forms had become extinct. The extinctions were considered a minor aspect of the evolution of life.

At the beginning of the seventies and during the eighties of the last century, interest increased with works like the one of Raup and Sepkoski (1982) that attempted to quantify the magnitude of extinctions throughout the history of the Earth. Sepkoski (1991) published a magnificent compilation of the marine fauna fossils and the evolution of the number of genus throughout the history of the Earth. He correctly concentrated on the marine fauna, which is the best conserved, and took into consideration the genus, a well defined taxonomic unit, and not the species which are more subject to opinion. The geological timescale was made more precise, not only in relation to the exact limits between the different periods but also their duration. The publication of "A Geological Timescale" (Gradstein *et al.*, 2004) presented to and approved by the 32nd International Geological Congress in Florence in August 2004, finally provides a reliable chronological reference to propose reliably the rhythm of the extinctions. The graph of the biodiversity shows a series of peaks corresponding to the moments of maximum extinctions separated by periods of time in which the diversity is constant or rises due to the appearance of new taxonomic groups (Fig. 8).

This renovation manifests itself as a first stage of extinction of ancient forms and a second "explosion" of new forms. Today, it is believed with relative certainty that the history of the Earth and Life do not advance clockwork regularly and continually or like the orbits of the planets around the sun. Its rhythm coincides more closely to the "life of a soldier, consisting of long periods of boredom, separated by short moments of agitation and terror" (Rudyard Kipling).

5. 2. The great extinction at the end of the Permian

The crisis at the end of the Permian is the most important and best studied. It produced an almost total renewal in the flora and fauna which had lived in the Paleozoic. Some authors have named it *the mother of all extinctions* (Erwin 1993). The most important renovation of the flora and fauna in the last 540 million years of the Earth's history occurred in a relatively short time. The maximum period of extinction when the largest part of the species was eliminated lasted between 600,000 and one million years (only 200,000 to some authors).

The recovery from this huge reduction of biodiversity and life on Earth took much longer, almost all of the Lower Triassic, about six million years (Hallam, 1997). This "extinction" did not cause all the life on Earth to disappear. Some areas of the Earth were not affected, or at least not to such a great extent, and the life which inhabited these areas, the so-called "Lazarus" groups (which survived rather than were revived!) began the later repopulation of the Earth. It appears that one of these refuges was situated in the present Gulf of Oman, as it was here that fossils have been found throughout all the record between the Permian and Triassic.

The extinction was especially severe in the fauna of the coastal areas. Between 85% and 95% (according to the authors) of the marine species disappeared; amongst them whole groups like the trilobites and fusulinids. Others lost the majority of their representatives like the brachiopods and the bryozoa. In the cephalopod group, the goniatites

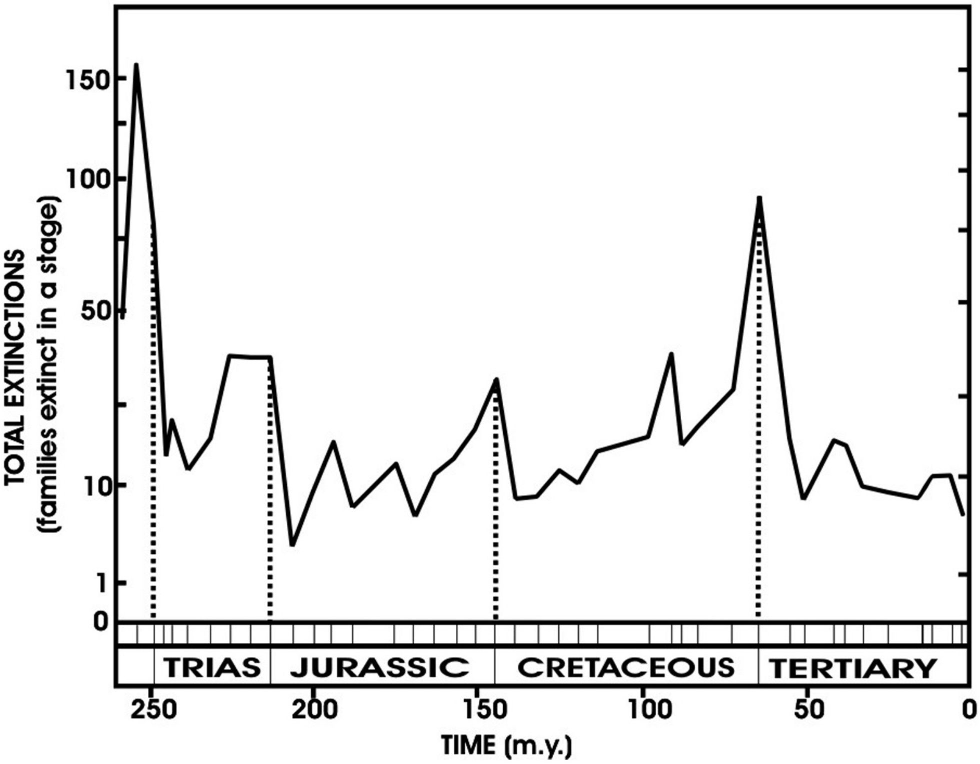

Fig. 8.- Extinction intensity over the past 250 m.y. for marine animal families. After Sepkoski and Raup (1986).

Fig. 8.- Intensidad de las extinciones a lo largo de los últimos 250 m.a. para las familias de animales marinos. Obtenido de Sepkoski y Raup (1986).

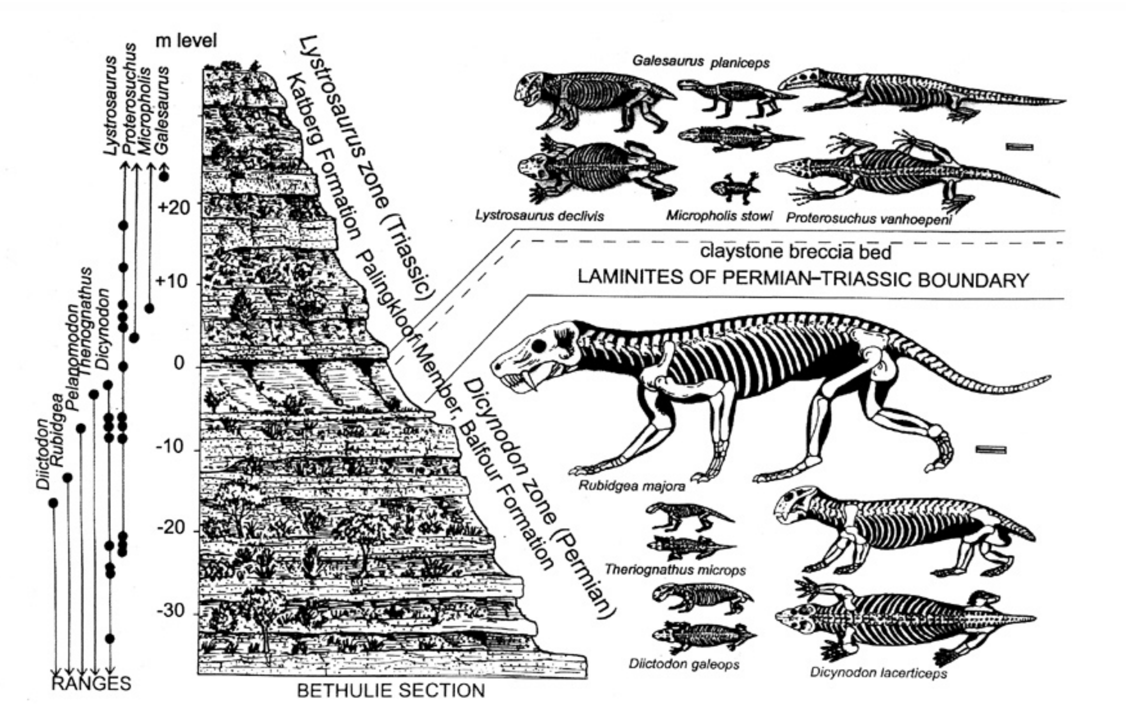

Fig. 9.- Permian-Triassic general stratigraphic section and the vertical distribution of terapsids at Bethulie (Karoo Basin). After Retallack (2003).

Fig. 9.- Columna estratigráfica general para el Pérmico y el Triásico y distribución general de terápsidos de Bethulie (Cuenca del Karoo). Obtenido de Retallack (2003).

were substituted by the ceratites (ammonites), and in the corals, the tabulates and tetracorals for hexacorals. The bentonic fauna in the Paleozoic were dominated by brachiopods, sessile crinoids, echinoderms and bryozoa, while in the Triassic there were mostly bivalves and gastropods. This fact, together with paleogeographic studies, show that a slow marine regression began in the Lower Permian, and accelerated as far as and culminating in the Upper Permian, leaving the largest ever emerged area of land in the last 500 million years. A transgression began at the start of the Triassic, when the waters returned to cover a part of these emerged lands, but the fauna which had lived there had become extinct forever and the new platforms became colonized by new species.

The renovation of the plant kingdom was also important but not as well known due to the difficulty in identifying plant remains. It should not be forgotten that in many cases only the pollen or spores have been preserved and we do not always know to which plants they belong to. It is difficult to asses the precise moment this renovation occurred and to know if it was contemporaneous with the marine crisis (López-Gómez *et al*., 2005). The rich and relatively abundant Thuringian flora at the end of the Permian, dominated by the conifers, disappeared suddenly from the stratigraphic series and the Triassic materials which follow are practically azoic. It was not until the middle Scythian that plant remains reappeared, these were lycopsid-dominated floras whit proliferation of *Pleuromeia* (Steiner *et al*., 2001; Grauvogel-Stamf, 2005), poorer in species and more primitive than at the flora of the end the Permian. The restoration of the Triassic vegetation begins with these lycophytes, very primitive and resistant ferns capable of living in highly saline environments which spread across all the continents. The plants with pollen (conifers) did not reappear until the end of the Anisian and did so with the genus *Aethophyllum* (Rothvell *et al*., 2000), the only herbaceous conifer which has existed and which was very resistant and so was able to colonise the new emerged lands at the beginning of the Mesozoic.

The insects were the least affected group by this renovation, although nine orders of this group disappeared and others were drastically reduced. The Permian/Triassic is the only moment in the insect evolution when several insect orders became extinct concurrently. Practically all those which survived at that time are present in today's fauna (Béthoux, 2005). The *blattoidea* (beetles) bore the crisis with almost no problems and have arrived to the present day with hardly any "modifications". The disappearance of the gigantic insect forms which lived in the Carboniferous and Permian is significant, like some dragonflies such as the Permian *Meganeuropsis* with a wingspan of 75cm. It is thought that this was due to the impoverishment of the atmospheric oxygen. The atmosphere oxygen content was higher at the end of the Paleozoic than today, but at the beginning of the Triassic dropped to the present lower levels.

The amphibians were the most affected group by extinction among the vertebrates, whilst the reptiles were the protagonists of the Mesozoic era, and they did not lose this protagonism until the extinction of the Dinosaurs at the end of the Cretaceous permitted the diversification and dominance of the mammals. Studies in South Africa (Retallack *et al*., 2003; Smith *et al*., 2005) have revealed very interesting data about the evolution of the vertebrates and the causes of their extinction. In this region the Permian and Triassic alike are represented by a thick succession of red, detritic continental sediments, the Karoo group, deposited from the Carboniferous to the Lower Jurassic (Fig. 9). Abundant therapsid (reptilian ancestors of mammals) remains have been found there. The limit between the Permian and the Triassic coincides with a very important faunistic change. The Permian has 34 different therapsid genus, *Dicynodon* being the most predominant. Only four genus survived as far as the Triassic, among them *Lystrosaurus* which had existed in the Permian but was scarce. Other new forms also appeared but the previous diversity was not recuperated. Research into their anatomy demonstrates that the genus that survived had an improved respiratory system, which allowed it to breathe better in an atmosphere poor in oxygen. This confirms the change in the atmospheric composition, which the insect evolution also demonstrates. Recent studies (Smith, 2005) have demonstrated a 65% mass extinction of Late Permian terrestrial vertebrates at the Permian-Triassic boundary lasting some 300.000 years, and an lesser extinction event (31%) approximately 160.000 year later in the Early Triassic.

Lithostratigraphic studies of the rocks of the Karoo basin (South Africa) also provide some interesting information (Smith, 1995). It is a sequence of detritic material 12,000 metres thick accumulated in an enormous intracratonic basin (500,000 km^2 approx.) and represents a continuous record for almost 100 million years (from the Late Carboniferous to the Jurassic). They consist of fluvial deposits with alternating beds of sand, gravel and clays, and the series is crowned by a basalt formation. Between the different fluvial sequences there are layers of paleosols containing plant remains, mainly root moulds and pollen grains. The texture, structure and granulometry of the materials shows their fluvial origin and also allows us to discover the characteristics of the rivers that deposited them (Hancox *et al*., 2002). The lower part of the series, characterised by the predominance of *Dicynodon*, corresponding to the Permian, was sedimented in wide plains by high-discharge meandering rivers. The higher part, where presence of *Lystrosaurus* is predominant (Triassic), shows deposit characteristics of an erratically flowing, low discharge rivers, which joins together and separates in a reticulated network, or braided rivers.

Fluvial dynamics is sufficiently understood today to confirm whether this change in the fluvial system corresponds to a climatic evolution being more humid and cold in the lower sequence and progressively more arid and warmer in the upper sequences (Ward *et al*., 2000). Studies of the paleosols, where the fluvial complexes often culminate, confirm this interpretation. The abundant vegetation covering the region during the Permian sustained the lives of numerous herbivorous therapsids, which were unable to subsist when the climate changed and the vegetation became impoverished; they were substituted by *Lystrosaurus*, which was more resistant and had a curious nasal appendage, which is believed helped them to unearth the rhizomes typical of arid vegetation. It is important to remember that the variation of the fluvial system was also conditioned by the coeval tectonic activity of the basin, important in this region. Research into the detritic Buntsandstein sequences of the Iberian Ranges shows a fluvial system evolution very similar to that described above. If this fact is confirmed at other sites, it would be the guarantee that the change is not a consequence of some regional tectonic conditions, but reflects the climatic evolution of the planet and as such would have chronostratigraphic value (Arche *et al*., 2005).

Notwithstanding, the Karoo sequences can serve as a reference, at least a methodological one, for the study of the continental Permian and Triassic periods of other basins. At the 32nd International Geological Congress held in Florence in August 2004, various articles about the study of therapsid footprints from different sites were presented: New Mexico (USA), Lodève (France), Esterel (France), and the Central European Permo-Triassic basin (Germany and Poland). Scarce data has been found in Spain, the most important being in the Cantabrian Mountains (Martínez García *et al*., 1994). This technique is a new approach, which will doubtlessly give good results for the correlation and delimitation of the continental sequences in the Permian and Triassic.

5.3. "The golden spike"

To understand a specific event it is fundamental to position it in time, to know exactly when it occurred. This is the only way to see the motives causing to it and how it was influenced by the circumstances in its environment. Therefore, to understand why these massive extinctions were produced, it is necessary first to date them with maximum precision, a laborious task which only now is practically completed. The term *Permo-Triassic* has been used for a long time in the study of the continental sequences in the majority of Europe to designate the set of red, detritic materials between the Carboniferous and the Muschelkalk (mid-Triassic calcareous-dolomitic). In the 1920s, Hans Stille and the German school introduced the first separation criteria: the unconformity produced by Hercynian Orogeny (Stille, 1924). Soon it was discovered that things were not that simple, as the orogenic movements are not instantaneous and therefore not well defined in time. It was later agreed that it was necessary to divide them into different phases. The Palatine Phase was supposed to be situated on the boundary between the Triassic and the Permian, and thus would serve to delimit these two systems. The Saalian Phase, would be intrapermian and would allow the separation of a higher and lower Permian. This solution, simple to understand and apply had an inconvenience: it was untrue. We now know that the unconformities have only a local chronostratigraphical value. A large part of Europe was subjected to numerous tectonic pulsations throughout the Permian and Triassic, which produced different unconformities, and disconformities of local extent and for this reason cannot be used as dating criteria.

The application of paleomagnetism in this research represented a great breakthrough in the delimitation of the ages of the rock formations. Identifying a marked polarity reversal situated exactly between the Permian and the Triassic would once again offer a solution to the limit problem. Such a reversal was apparently found a hundred kilometres to the South of Sydney (Australia) near lake Illawarra. This discovery caused great excitement but it was later shown to have little value as stratigraphic marker as the Illawarra reversal was situated between a basaltic formation and overlaying conglomerates, and it was clear that there was a discontinuity between these two series, a sedimentary gap of unknown duration. The register was, as such, incomplete and did not serve to situate any limit. That is not to say that paleomagnetism is not useful for establishing correlations, but the Illawarra reversal is intrapermian and do not mark, as was originally supposed, the limit between the Permian and the Triassic.

It was necessary to look for the delimitation in a series which would guarantee a continuous record and, therefore, more accurate biostratigraphic dating criteria; these characteristics are generally only found in marine series. As was previously explained, the most suitable place for research was Meishan, in SE China (Yang *et al*., 1987). After many years of discussion it was decided to position the spike in a concrete level of this series (level 25) which marked the boundary between the series deposited at the end of the Primary and those beginning the sedimentation of the Secondary (Gradstein, 2004).

When it was finally possible to identify the precise point corresponding to when the mass extinctions occurred, the appropriate way to proceed in the search had been found. The first study of this section of Meishan was carried out by Chinese geologists at the beginning of the 80's. The exact level, which they put forward as a limit, is a layer two to five centimetres thick of light grey clays. These clays have a high quantity of iridium, an element which, although found in small quantities in volcanic ash, is much more abundant in meteorites. A high quantity is also found at the level which marks the limit between the Secondary and the Tertiary, representing the moment when it apparently seems that the impact of a meteorite had caused the extinction of the dinosaurs. It seemed, therefore, that they had found the "culprit" of the catastrophe: "The exterminating meteorite"! At the 28th Congress of Geology held in Beijing in 1989, at which this layer was proposed as the boundary, more than thirty articles supported the theory of the meteorite impact based on the characteristics of the clay layer. This level with iridium anomaly has been located afterwards in other sites in the world and continues to create maximum interest. At the 32nd Geological Congress in 2004, held in Florence, the origin and significance of this level occupied many sessions, but in the twenty-five years separating these two congresses the way of concentrating on this problem has changed completely.

Nowadays, stratigraphy is not the "science of strata"; the concept of "strata" is a model of the past. Nowadays the object of study is the "sequence", the succession of materials where a process is registered. We now know that it is necessary to analyse a sequence in order to unravel a process which lasted a certain time. It is not the presence of a specific element in a determined layer which can give the answer, but the way in which its proportion evolved vertically (or in time) and with other elements (Mei, 1996).

Holser (1984) and Holser *et al*., (1986), began to study the evolution of the composition of the water in the oceans throughout the history of the planet. This study was based on the geochemical analysis of sediments deposited in long-gone oceans. One of the first elements he studied was the carbon isotope, C^{13}. It was shown that C^{13} is more abundant than C^{12} in organic matter, and as such, the proportion of this element in carbonatic rock demon-

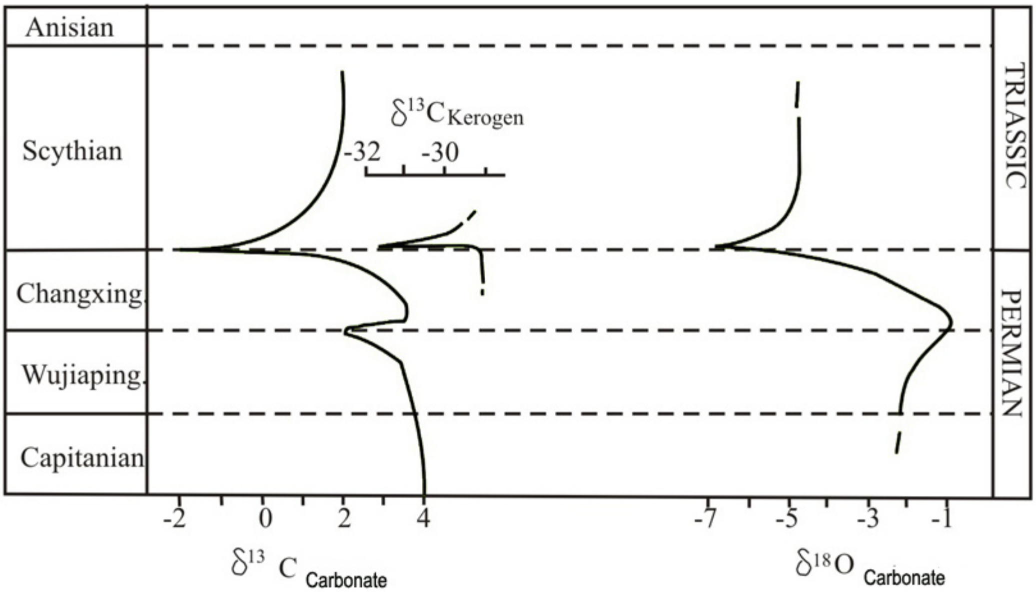

Fig. 10.- C and O stable isotope variations from the Middle Permian to the Middle Triassic. From Hallam and Wignall (1997). Reproduced with permission.

Fig. 10.- Variaciones de los isótopos estables de C y O desde el Pérmico Medio hasta el Triásico Medio. Reproducido de de Hallam y Wignall (1997), con permiso.

strates the greater or lesser influence of the organic matter in the rock's origin. It was soon discovered that there was a clear alternation of sediment layers rich in C^{13} and others where the "productivity of living beings" was dramatically reduced. Holser´s studies began studying the Permian and Triassic in the Rocky Mountains where the results were so interesting that new works were subsequently applied to the Permian and Triassic rocks in the Alps of Austria and Switzerland, the Himalayas, the South of China and in Greenland (Baud *et al*., 1989; Sephton *et al*., 2002). The results in all the sites were the same (Fig. 10). There was a reduction in C^{13} at the end of the Permian and a slow recuperation at the beginning of the Triassic. If there are a stepwise decline of C^{13} during the Late Permian the greatest decline coincides with the limit between the Permian and the Triassic deduced from the research of ammonoids, conodonts and fusilinacea. The carbon isotope (C^{13}) reflects the importance of the biomass in the formation of the carbonates. In other words, geochemistry confirmed the conclusions that had been deduced by fossil studies: there was a marked decline in the number of living beings inhabiting the Earth at the end of the Permian and "life" slowly recuperated throughout the Early Triassic. The graphical curve representing the quantity of C^{13} is the numerical expression of the biotic crisis which palaeontology demonstrates (Paine *et al*., 2004; Corsetti *et al*., 2005).

The isotopic variation of oxygen (O^{18}) was studied in the same way (Fig. 10). We know today that this variation in the composition of carbonatic rocks reflects the temperature of the waters in which they were deposited. The boundary between the Permian and the Triassic is clearly identified by a sharp drop in this isotope which demonstrates an important rise in the global temperature of the planet followed by a slight cooling.

The variations of other elements have also been studied during the same interval. The variation in the ratio between the two isotopes of strontium (Sr^{87} and Sr^{86}) (Fig. 11), is also very illustrative, although the limit was not marked exactly. It has been shown that this ratio reflects the quantity of continental sediments which arrive today to the oceans (Septon *et al*., 2005). It is supposed, therefore, that the ancient series could give an idea of the relative extension between the marine and continental areas, and also the intensity of erosion of these areas. Explained in another way, it would be an index of "continentality", that is to say the predominance of the continents over the oceans, which characterises the end of the Permian and the beginning of the Triassic.

Research into the isotope of sulphur (S^{34}) has a very similar evolution (Fig. 11) and allows us to estimate the amount of oxygen the ocean waters contained. The sulphur deposited in anoxic environments is always poor in this isotope. This fact would be another index of the difficult conditions for life, which prevailed in the seas at the end of the Permian - warm waters, low in oxygen and as such with low biological productivity. These data, together with those provided by other isotopes, give us sufficient information to be able to reconstruct what happened at the moment of transition between the Paleozoic and the Mesozoic eras.

5. 4. The whys and wherefores

Research into the relation of cause-effect marks the beginning of scientific reasoning, eliminating the need for supernatural reasons to explain poorly understood phenomena. Charles Lyell, the pioneer of scientific methodology in Geology ("Principles of Geology", 1830-1834) claimed that the gravel and sand deposits around London could not be attributed to the Biblical flood; it was necessary to look for the origins in the ancient stretches of the meanders of the Thames. As a result, it is said that Lyell introduced the principle of "actual causes", in the sense that the philosophers of that time gave to *vera causa* as a real and observable fact, as opposed to magical or supernatural causes (Virgili, 2003).

Today, scientific language has changed. From the end of the 18th century, the concept of cause, and over all, the cause-effect relationship, has gone into crisis and we make do with that of "process and result". We believe that observation allows us to discover that some specific results are produced by the consequences of a fact which sets off a process, but this does not mean that the "triggering fact" is "its cause". For example, if you open a window, it is only this action which allows light to enter. The "cause" of the illumination is clearly not the fact of opening the window, as it is only the action that lets light in. The "cause" of the illumination is that there is sun outside, or a full moon or illumination. In other words, the causality is not directly "observable", only "attributable", like the results of a mental thought which might be correct or incorrect. Moreover, sometimes there is not only one cause, but varied which act together. The object of science is not to discover the causes, but to understand the processes in order to predict results and modify them, if possible, as necessary. The same happens in human life; when things are bad, it is not a case of "find who's to blame", but better to clarify "why it happened" so as to know how to avoid it in the future.

In the case of this extinction, the objective data are indisputable. The extinction and renovation of the flora and fauna coincide with some important variations in the sea level, climatic changes and also changes in the composition of the atmosphere and the ocean waters. But it is not so easy to say that all of these changes were produced together at this moment. Why so much intensity and so much movement on our planet in a little less than a million years?

The first explanation put forward, based on the study of the level of "boundary clays" observed in the outcrops of SW China, was the impact of a meteorite. In its favour is the significant presence of metals from the platinum group at this level: iridium and osmium and tiny spheres which appear to be of extraterrestrial origin. It was also an explanation which similar to that invoked for the extinction of the dinosaurs at the end of the Cretaceous: it is the same cause. When the process was analysed in more detail, the first objections arose: the extinction did not begin abruptly, but rather as a result of the intense modifications in the atmosphere and the ocean waters as described before. It should be understood that the biological extinction was a result of a complex process which took a certain time span.

One of the most prominent proofs of the intervention of an extraterrestrial body is the presence of anomalous high

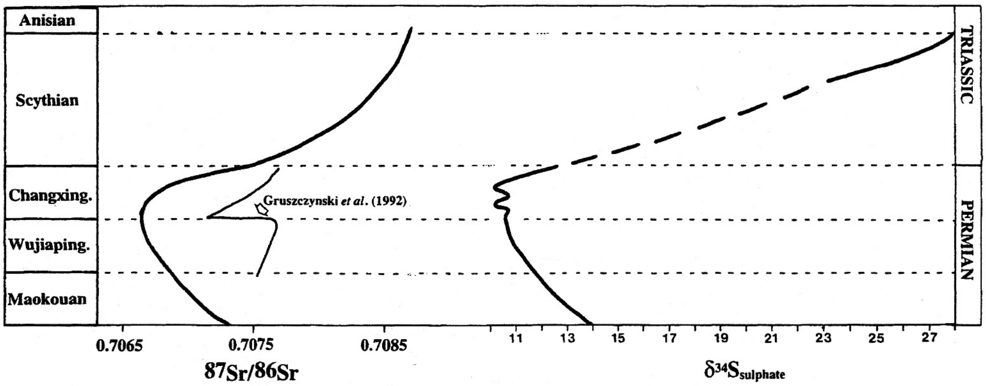

Fig. 11.- Strontium isotope trends during the Late Permian and Early Triassic (modified from Martin and Macdougall, 1995). Superimposed data of curve from Gruszczynski *et al*. (1992) show a different tendency, although they are probably affected by diagenetic alteration. From Hallam and Wignall (1997), reproduced with permission.

Fig. 11.- Tendencia del isótopo de Sr durante el final del Pérmico y el comienzo de Triásico (modificado de Martín y Macdougall, 1995). Los datos de la curva superimpuesta de Gruszczynski et al. (1992) muestran una tendencia diferente, aunque probablemente está afectada por alteraciones diagenéticas. Reproducido de Hallam y Wignall (1997), con permiso.

content of iridium, although it has been demonstrated recently in Kilauea (Hawaii) that this metal can derive from the gas emanations of volcanoes (Fluteau, 2004). Recently, some complex carbonic molecules have been found in these "boundary clays", the fullerens, which are spherical in shape (like a tiny football ball) and conserve a quantity of the rare isotopes He^3 and Ar^{36} which are more abundant in outer space than on the earth (Becker *et al*., 2001). These elements are also present in the boundary between the Cretaceous and Tertiary. It is clearly not possible to rule out the impact of a meteorite or an asteroid, but what is clear is that this impact would not have been sufficient to produce so many modifications in the atmosphere or the oceans, nor would it explain the phenomena which occurred during the preceeding few million years which caused this mass extinction.

Another objection is that the impact crater cannot be identified with any certainty. Nowadays, it is thought by some that this crater is located in the continental platform of NW Australia, at Bedout (Becker *et al*., 2004). It would have a diameter of between 200 and 600km and correspond to an impact of an asteroid of between 30km and 60km in diameter or a comet of between 15km and 30km in size. This interpretation has been intensely debated (Koeberl *et al*., 2002; Jones *et al*., 2001), and a recent research study (Müller *et al*., 2005) demonstrates that whereas the resulting morphology at Bedout could be similar to an impact crater, however, the internal structure is not compatible with the one produced by an impact. These latter authors consider that this morphology could be the result of a rifting process. Nor do the sedimentary series of the contemporary areas of the alleged impact show any signs of the enormous wave which would have been produced in the marine environment by such a great commotion. The majority of the authors who presently support this hypothesis of the extraterrestrial object impact think that it did not directly cause the environmental modifications responsible for the extinction, but would have done so indirectly. The strength of the impact would have "torn" the Earth's crust (Kaiho *et al*., 2001; Glikson, 2005) and caused an extrusion of material from the earth's mantle that would have triggered volcanic processes. This theory, however, is not widely accepted by the scientific community (Melosh, 2001; Phipps-Morgan *et al*., 2004, 2005).

The possibility of other extraterrestrial causes has also been considered such as the collision with a low-density comet, which would have produced a large modification of the chemical composition of the atmosphere and seawaters. Another explanation is that the solar system might have encountered an interstellar cloud or a flow of high-energy particles that, by destroying the ozone layer, allowed the passage of "deadly radiation". Recently (Rohde *et al*., 2005; Kirchner *et al*., 2005) the curves of the extinctions of marine animals over the last 500 million years have been studied, and it has been demonstrated with sophisticated mathematical methods that the variations in biodiversity fluctuate with a periodicity of 62 ± 3 million years. They claim that this shows evidence of "extraterrestrial or astronomic origin", although they do not rule out the possibility that this periodicity obeys a mechanism of the evolution of life itself or of the internal geodynamic processes of the Earth.

Evidently, all of these events are possible, but Geology is not a speculative discipline which tries to explain what may have happened, rather it attempts to clarify what really happened by observing and studying the characteristics of the stratigraphic series where, one way or another, the facts have remained registered. In order to find the solution we must concentrate our energies on the search and interpretation of observable evidence on our planet which can explain the paleontological, lithostratographic and geochemical characteristics of the series. The diagram of figure 15 summarises the proposal of the enormous volcanic eruptions in Siberia during this period as the principal agent of the crisis.

The main argument in favour of this hypothesis is that these eruptions occurred and the resulting materials can be observed. The Permian is rich in volcanic rocks everywhere, but in central Siberia, in the Tunguska basin, there are immense lava flow deposits, which correspond to the most voluminous and explosive volcanic eruptions on the Earth in the last 500 million years at least. This region has been intensively explored as the world's most important reserves of platinum, nickel, cobalt and palladium are found here in the mines of Noril'sk and Talnakh. The outcrop has a surface area of four or five times the size of the Iberian Peninsula but as these volcanic rocks are only partially exposed, being covered in a large part by the Triassic and Jurassic, it is highly probable that the extension is greater. In the Maymecha-Kotuy region, where it has a thickness of about 6,500m, radiometric dating of zircon from the base levels has given an age of 251.7 ± 0.3 million years, and at the higher ones, 251.1 ± 0.3 million years at the base. This means that this immense lava mass emerged in less than a million years and appeared precisely at a time which coincides with the boundary between the Permian and the Triassic, and at the moment of the mass extinction. In other Siberian sites, such as central Kazakhstan, other similar formations have been found with the same age, or slightly older (Yakubchuk, 2003; Campbell *et al*., 1992). There is also an important volcanism in China located in the Permian-Triassic limit, however, the characteristics of these latter materials are

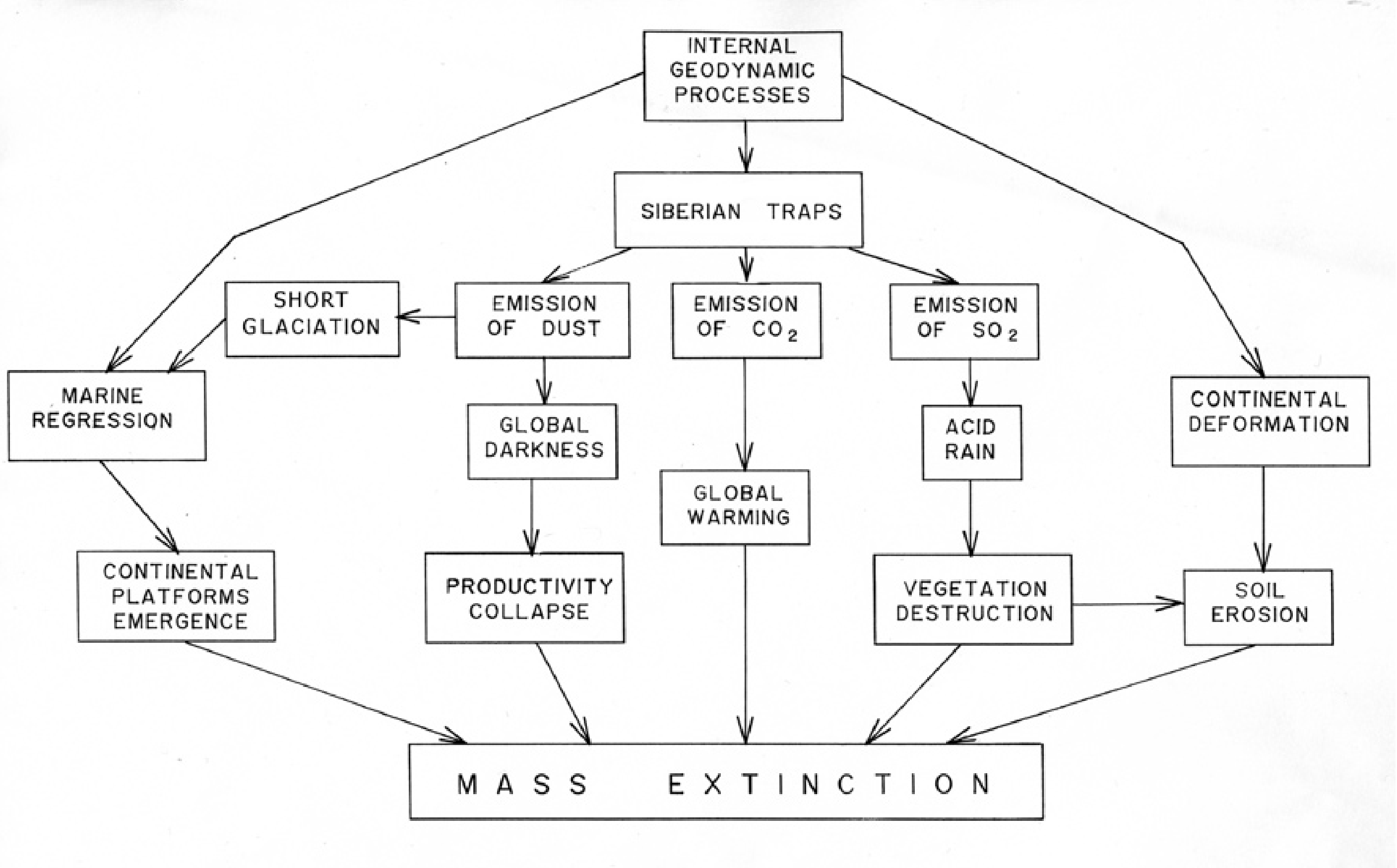

Fig. 12.- Chain of events and the supporting evidence of the volcanic influence for the Permian-Triassic mass extinction.
Fig. 12.- Encadenamiento de eventos apoyando la idea de la influencia volcánica en la extinción masiva de la transición Pérmico-Triásico.

very different to the ones of the Siberian floods. In China it consists of massive eruptions of intermediate to acidic character with probably important dust injections into the atmosphere (Yin *et al.*, 1989).

The effects of these immense volcanic eruptions, which projected rivers of fire across the earth, and clouds of dust and toxic gases into the air, seem to be more than sufficient to explain the subsequent climatic and biological crisis which is here represented (Fig. 12). The sulphurous gases projected into the atmosphere caused acid rain which "burn out" the vegetation, exposing the rocks and therefore accelerating their weathering and erosion (increased Sr^{36} and Sr^{37}). The acid rains and the river waters carried the pollution to the oceans (Sephton *et al.*, 2005). The huge quantity of dust which was projected into the atmosphere prevented the passage of light and heat from the sun. This impeded the function of chlorophyl in the plants and also caused a short, but intense cooling, resulting in a glaciation. The viability of life, both marine and terrestrial, was seriously affected and the productivity of organic material (C^{13}) decreased. Another gas emitted in great quantity from the volcanoes was CO_2, which contributed to the anoxic conditions of the oceans (Courtillot *et al.*, 2003; Courtillot *et al.*, 2004) and finally gave rise to a global warming (O^{18}) (Montañez *et al.*, 2004). In this dramatic situation it is not surprising that what Erwin (1993) named the "mother of all extinctions" occurred. Recent studies (Egger and Brückl, 2006) also demonstrated that the voluminous flood basalts, associated igneous intrusions and widespread pyroclastic deposits linked to the North Atlantic Igneous Province starting in the early Paleocene and lasting to the Paleocene-Eocene was probably related to drastic climatic change of the early Eocene. Contemporaneous with this period of volcanic activity there was a large increase in CO_2 episode in the atmosphere (Pagani, 2006) and a sharp drop in the C^{13}/C^{12} ratio in the oceanic water. Pagani supports believe this is the cause of the extreme global temperature rise that provoked the great biological crisis, the large number of extinctions (large reptiles, bentic foraminifera, etc..) and the rising of next forms, such as the primates. This crisis marks the Mesozoic-Cenozoic boundary. On the other hand, Baroni *et al.* (2007) have also demonstrated rapid changes in the composition of gas of volcanic origin once it reaches the stratosphere and the impact it produces. They observed how sulfur isotopic composition of volcanic sulfate from the recent Agung and Pinatubo volcanoes eruptions recorded in Antarctic snow can change in a monthly time scale the composition from sulfur dioxide to sulphuric acid once they reach the stratosphere.

There is one element which was of the greatest importance to ocean life: the marine regression (Hallam, 1989), or in other words, the huge drop in the sea level which was produced at the end of the Permian. The life in the ocean now, as in the Permian, is greatly concentrated on the continental platforms where the waters are shallow, lit by the sun and rich in nutrients. A drop of the sea level would have made these platforms emerge and dry out, killing the plants and animals living there. A few million years later, in the Middle Triassic, the sea levels began to rise again and the waters invaded the edges of the continents and slowly the marine life began to recuperate. It began mainly with the most primitive life forms, such as algae and bacteria with a very low productivity of carbonatic skeletons. This large oscillation in the sea level could not have been solely due to the formation and later melting of glacial ice linked to climatic change. There must also have been an active movement of the continental blocks and the ocean beds.

It seems clear today that both volcanism and the variations in the sea levels were the result of a profound geodynamic imbalance in the Permian supercontinent (the Pangea), an imbalance between the lithospheric plates and also in the deeper areas of the Earth. It is thought that a hot spot was produced in the lower part of the Earth's mantle which caused a mantle plume (Davies, 1999; Olsen, 1999; Philipps-Moran *et al*., 2004, 2005). The melting together of the materials and the rising pressure were the causes of the volcanic eruptions. This dynamic would also have generated a uplifting of the continental block, a fact which explains the relative drop in the sea levels. The reality was far more complex, as, for example, volcanism was not exclusive to Siberia, but found in many sites of the ancient Pangea and throughout the Permian. This period was an age of profound imbalances, as much on the surface as in the interior of the Earth. An Earth already unbalanced by the distribution of the continents and the oceans: one hemisphere covered by water and the other by all the continental plates. This is something that has never occurred since then. Throughout the Mesozoic and Cenozoic our globe has been redistributing its continents and oceans more or less harmonically, looking for a more suitable equilibrium to the dynamic of its rotation. It appears evident, therefore, that "the mother of all extinctions" was the consequence of a profound and relatively rapid alteration in the environment connected to geodynamic processes caused by the internal energy of our planet. Some scientists consider that this periodicity, demonstrated by Rohde *et al*. (2005) and Kirchner *et al*. (2005), is proof of "extraterrestrial" intervention, but it could also be the "Earth's heartbeat", the "pulse of its energy". In the same way, Courtillot (1999) have recently shown a clear comparison of the ages of the main volcanic traps and mass extinctions during the main periods and epochs (Fig. 13).

5.5. The crises: disasters or renewals?

We must understand that life on our planet has never had a "peaceful history". "Mother Earth" has often behaved like "Snowwhite's stepmother". At any rate, if we make a balance of history, the end result is very positive: from the bacteria to human beings, and from the difficult conditions of life in the Palaeolithic when fire has not been discovered to the comfortable surroundings many of us live in today. The extinction at the end of the Permian was, without doubt, a disaster for all the animals and plants which became extinct, but this extinction allowed the living space left behind to become occupied by other forms; in general smaller and less "powerful", but with more capacity to adapt to changes in their living environment.

During the late Carboniferous and the Permian, the "mammiferoid reptiles" developed and evolved. The earliest mammal remains so far discovered, were found in Upper Triassic deposits in Wales: the *Morganucodon,* a small form similar to the present day insectivores. This and other similar forms (*Docodonts*) developed throughout the Mesozoic in the shadow of huge reptiles. Only when the great extinction at the end of the Cretaceous wiped out the gigantic reptiles were the mammals able to become the dominant group on the continents and also to colonize the sea waters (whales and dolphins for example) and the air (bats), just like the reptiles had done during the Secondary. With the passage of time, at the end of the Tertiary, an evolutionary branch of the primates would give rise to such an "important" species as the human one which would almost certainly not have appeared if it had not been for the mass extinctions caused by the crises at the end of the Permian and the one which concluded the Cretaceous a hundred million years later.

Therefore, is it correct to consider these crises as "catastrophic disasters"? Is there any sense in presenting the future as a path resulting in a final disaster?

6. The effect of climate changes

All this happened a long time ago: 250 million years! But this perspective is vital to understand the future. Geology allows us to decode the Earth's history, a past which has remained written in the materials and structures which make up its crust. It is indispensable to un-

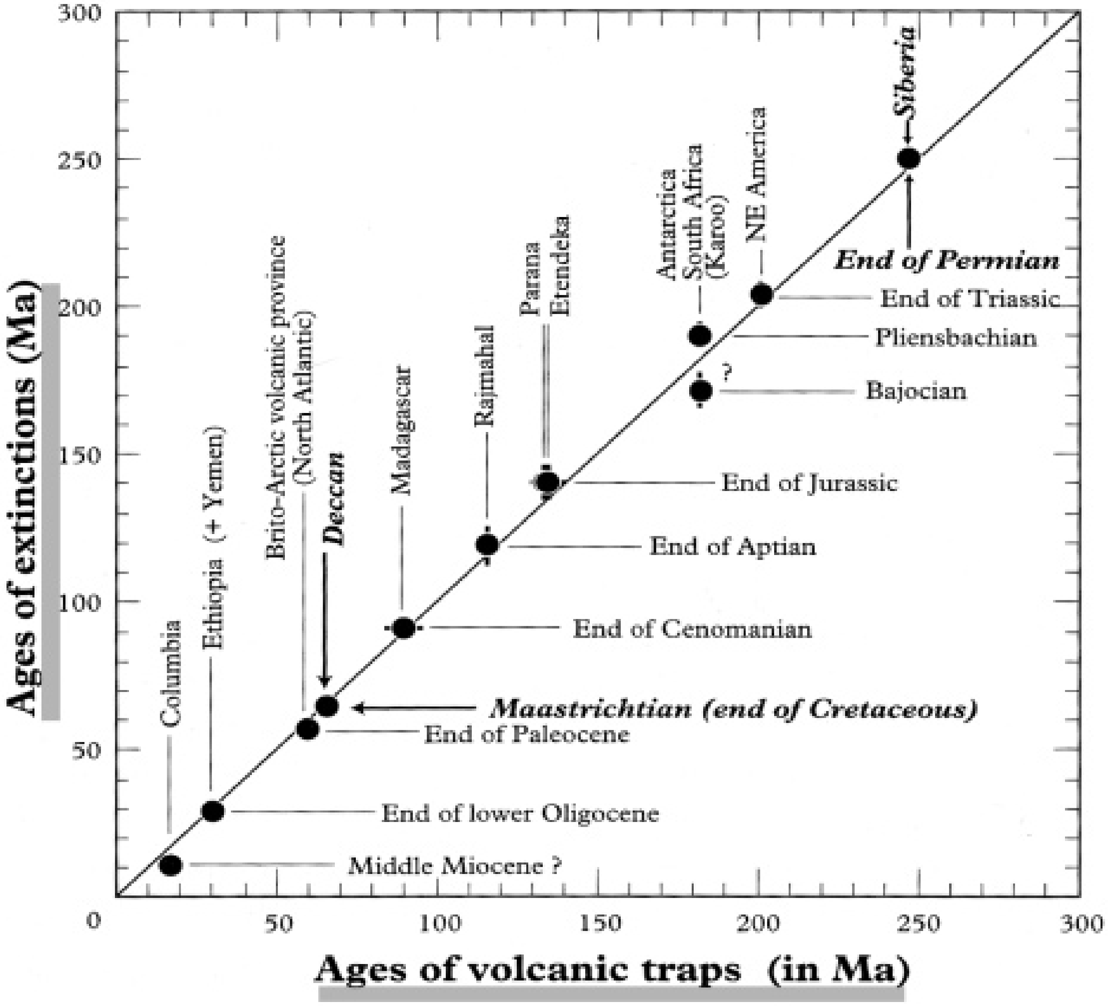

Fig. 13.- Comparison of the ages of the main traps and main extinctions since the Permian. Reproduced from Courtillot (1999), with permission.

Fig. 13.- Comparación entre las edades de las principales manifestaciones volcánicas y las principales extinciones masivas desde el Pérmico. Reproducido de Courtillot (1999), con permiso.

derstand this record in order to discover “the rules of the game”. Only if we can understand these “rules”, or the processes which have dominated the Earth’s history, we can manage the present and future of the planet in the most suitable way; a future which is also our future.

One clear conclusion from this history is that the climatic conditions of our planet have been constantly changing throughout geological time. These variations, logically, depend on the amount of solar energy that reaches the surface of our planet and are controlled by several different factors, some dependent on the Sun, others on the Earth. Without going into detail, it can be said that the astronomic factors are basically the intensity of the solar radiation, the distance from the Earth to the Sun and the angle of incidence of the solar rays to the Earth surface. Recent paleoclimatological studies, using complex calculations, allow us to study this evolution not only in the past but also in the prediction of the future.

However, it is also necessary to take into account that meteorological factors as the flow of solar energy reaching the Earth is profoundly modified by the transparency of the atmosphere which allows more or less solar energy to pass and also controls the heat which the Earth loses by irradiation. Apart from the influence of cloud cover, it is well known that a large increase in CO_2 provokes a greenhouse effect. On the other hand the particles suspended in the air protect the Earth from the sun’s rays. The effects of the ashes expelled by volcanic eruptions allow us to prove the importance of this fact. Research by NASA into the eruption of Pinatubo (Philippines) in 1991 is particularly demonstrative. A cloud of more than 22 million metric tonnes of volcanic dust rose to a height of 35km and soon covered a large part of the Earth. As a consequence of this, the average temperature of the Earth fell by between 0.5 and 0.7 degrees centigrade and this effect continued as far as 1993. Moreover, the SO_2 emitted caused increased “acid rain” when it transformed into sulphuric acid after reacting with atmospheric water vapour.

The reception of solar energy differs greatly between the continents and the oceans. The surface of the water acts as mirror reflecting the light and heat and the aquatic mass acts as regulator of the ambient temperature. As we saw earlier, the relative extensions of the land and oceans have varied greatly throughout the history of the Earth and above all, the distribution of the continental blocks has been modified. These factors not only influence the climate of each individual block but also have repercussions on the global climate of the planet as it modifies the atmospheric circulation and the marine currents. These parameters are much more difficult to evaluate than those of astronomic origin or those apparently ruled by random factors.

Clearly this is not the place for making a list of all the factors which modify the climate of our planet over time, but simply to outline the complexity of the problem and the number of factors which intervene. Moreover, it is important to insist that it is senseless to talk about climatic change in singular, because the climatic changes have been and still are constant and natural throughout the history of the Earth. Our planet (like all the bodies in the universe) are alive, obviously in a different way from animals and plants but this “life” implies a process of change over time. The image of “Gaia” by Lovelock (1979) describes this in a very valid way.

It is especially important to insist on the fact that the climatic system is so complex that future forecasts are difficult. It is clear that it is ruled by astronomic factors, which are being understood better every day and are being evaluated in a more precise fashion. There are also very valid models, which analyse the interrelationships between the composition and temperature of the atmosphere and the way the vegetation cover and the oceans condition and are conditioned by the atmosphere. However, the influence of geodynamic factors involved are still not fully appreciated or understood. There is a constant exchange of matter and energy between the lithosphere, the atmosphere and the ocean waters. For instance, the climate in 10 or 100 years from now cannot be calculated thinking only about the CO_2 emissions by human activity. The emissions associated with geological phenomena must also be taken into consideration and are much more difficult to evaluate, such as those from volcanoes, the continents and the sea floors. The ocean ridges are huge scars (more than 60,000km in total), which produce such voluminous emissions of gases that they are difficult to evaluate. In the same way it is very complicated to predict the volume of CO_2 captured from the atmosphere by the sedimentation of carbonates from marine plankton and the coral reefs.

Nowadays, there are some very accurate models which predict the future evolution of the temperature of the ocean waters, but it is not possible to predict the rise in sea level by only taking into consideration the increase in the water mass produced by the melting of ice due to the increase in temperature. The water cycle is not limited simply to a balance between sea water and that retained as ice, as the other variables which are much more difficult to create a model for must be taken into account, such as continental freshwater and clouds. It therefore deals with a very complex balance and with factors very difficult to measure.

The modification of the shape of the marine basins throughout geological time is probably one of the most complex and least considered aspects, and as such, the volume of water they may contain. It is often thought that the seabeds are inert and stable until catastrophes occur like those produced by the terrible *tsunami* that recently destroyed the coasts of the Indian Ocean. The contact between the lithospheric plates are active lines along which the structure and form of the oceans is modified. When these contacts are convergent between two colliding plates, as is the case in Indonesia and in other places in the Indian and Pacific Oceans, the accumulated tension produces sharp displacements which cause *tsunamis.* If the contact is divergent between two separating plates, as in the Atlantic Ridge, the movement is slow and continuous, but also modifies the shape of the ocean beds. The opening of the ridge increases the area of the ocean beds and subsequently the ocean’s capacity. It is well known that American and Euro-African Atlantic margins separate by a few centimetres every year, but the volume of water the ocean could contain has not been calculated and so it is not known how it might influence changes in sea level.

Another important factor to take into account when we talk about the variations in sea level is whether these changes are due to variations in water volumes or simply upward or downward movements of coastal terrain. It has been demonstrated that the Côte d’Azure and Costa Brava possess a slight, but continual ascending movement, while on the other hand, the Ebro and also the Po delta, on which Venice is built, are subject to constant subsidence. The sea level therefore is the result of all these and other factors, some at global level and others locally, but to sum up, the Earth’s coastlines are never modified uniformly, not even in one particular marine basin (Lambeck *et al*., 2002). The Earth system, or the lithosphere / atmosphere / hydrosphere complex, is much more complicated than what can be deduced from certain descriptions and evaluations often described in the media. But that is not to say it is less fragile, nor that humans are we less responsible for managing it adequately.

All living things modify their surroundings by the mere fact of existing; sometimes in a "positive" way, other times in a "negative" way; but all these values are in fact purely subjective because for example lichens which install themselves on bare rocks erode and wear them away allowing the development of other plants and, if the climatic conditions are favourable, a vegetable soil is produced and the rock is covered with life. This action has been positive for the vegetal covering but negative for the rock which has been degraded.

One of the most important modifications of the environment by the action of living beings occurred about 2,500 million years ago, at the end of the Archaic and the beginning of the Proterozoic, when the composition of the atmosphere was very different from today. The atmosphere contained no oxygen and so only anaerobic life was possible. The life forms were very primitive and among them were some tiny anaerobic bacteria, the cyanobacteria. These microorganisms "excreted" a gas as a waste product of their metabolism, which was very toxic for them: oxygen. In a particular moment, there were so many that the oxygen they produced "infected" the atmosphere and made their survival impossible. This "climatic change" was not, as such, positive for them as they disappeared, but conditioned the future evolution of life in a very positive way for us. The presence of oxygen in the atmosphere made aerobic respiration possible and also permitted the formation of the ozone layer, which protects living beings from cosmic radiation.

In the diagrams which show the climate variation over the last thousand, ten thousand and million years, it is easy to appreciate the rise of the "average temperature" of the Earth from the beginning of the 20th century, or since the appearance of anthropic $CO_{2.}$ But also large temperature variations can be seen not only before the industrial era but also before the appearance of humans.

Future changes must not be thought of as necessarily bad occurrences. Life and its environment today are the result of the sum of these changes. The transformation from the arid Pangea in the Permian to today's landscape has been an improvement. The development of the present day fauna appears to be superior to the jellyfish of the Precambrian.

All actions, small as they may be, modify the surroundings and have a cumulative effect which are difficult to control and evaluate. One good example of the importance of human activity, which may at first seem "neutral" but in fact considerably affected the environment, is the "neolithic revolution" which represented the beginning of agriculture and the exploitation of animals and subsequently the felling of woods to make fields for crops and pasture. A study of coastal marine sediments show that in the Neolithic there was a rise in the rate of the detritic materials in sedimentation produced by the soil erosion as a consequence of this deforestation. The history of the Earth and mankind are closely associated: they are in constant dialogue, but much too often it is a dialogue between the deaf!

7. Conclusions

The transition between the Permian and Triassic Periods represented one of the main climate and biotic crises of the Earth history. The analysis of this great crises allows us to reflect on the climatic changes over the length of the history of the Earth as well as on the interrelation between fauna, flora and environmental changes.

During the Permian a big supercontinent, Pangea, extended from pole to pole practically covering one hemisphere while an enormous ocean, Panthalasa, covered the other one. In the continent, life conditions were probably precarious and plants, insects and amphibians suffered an important decline. The Permian-Triassic transition was even worst, and between 85%-95% of marine and land species disappeared. Credit is given today to the theory that this biotic and climate crises was due to a very important volcanic activity that released enormous lava flows and projected dust and toxic gas into the atmosphere. Although all the Permian series are rich in volcanic rocks, they are specially noticeable in Siberia where, at the end of the Permian, a great lava flow occupies an area at least four times the size of the Iberian Peninsula. A marked regression of the marine waters undoubtedly contributed to the crises as resulted in the emergence above the water of the continental platforms where the majority of the marine species were concentrated and, as the habitat dried out, they become extinct.

Studies on palaeogeography show different landscapes for the Permian as climate and topography were very different along Pangea. Poles were covered by an important ice caps, mid latitudes and tropic were under temperate climates but the interior of the supercontinent was very arid. Through the Mesozoic, a great fissure opened up from north to south giving rise to the Atlantic ocean and, during the last 250 m.a., the continental blocks moved to where we find them today. At the beginning of the Mesozoic, in the Triassic period, the palaeogeographic characteristics were not much different from those of the end of the Permian, although the volcanic activity had lessened and the relief created by the Hercynian orogeny had been considerably worn down by erosion. Volcanic activity still continued, but it was not so important as it was in the Permian.

Signs of recovery in continental flora after the crises first appeared at the end of the Scythian (Lower Triassic) by means of fungus spores, but the return of the conifers did not happened until the Anisian (Middle Triassic). This recovery also affected to the fauna; the first mammals appeared as well as some of the species that nowadays are still living. In this sense, the Triassic could be understood as the reborn or "aurora" of the present-day world.

Acknowlegmements

First of all, I would like to thank the Real Academia de Ciencias y Artes de Barcelona that authorised this publication. Part of this text was included in my conference when I was made member of this Corporation. I also want to thank to the CIEMAT and Mark Pearson for their collaboration in the translation of the manuscript. I also want to thank the interesting and valuable discussions with different colleagues, in special with José López-Gómez, for the review of the manuscript and constructive comments; also with Alfredo Arche and Alfonso Sopeña, all of them from the Instituto de Geología Económica, CSIC-UCM, Madrid as well as with Aimon Baud from Lausane Geology Museum; Yin Hongfu, from Wuhan Geosciences University; Jean Broutin, from Pierre et Marie Curie University (Paris VI) and Giuseppe Cassinis, from Pavia University.

References

Alberdi, F. (1864): *Veberblick uber die Trias mit Beruecksichtigung ihres Vorkommens in den Alpen.* Stuttgart: 135 p.

Arche, A., López-Gómez, J. (1996): Origin of the Permian-Triassic Iberian Basin, central-eastern Spain. *Tectonophysics*, 266: 443-464.

Arche, A., López-Gómez, J. (2005): Sudden changes in fluvial style across the Permian-Triassic boundary in the eastern Iberia Ranges, Spain: Analylis of possible causes. *Paleogeography, Palaeoclimatology, Palaeoecology,* 229: 104-126

Arche, A., López-Gómez, J., Marzo, M., Vargas, H. (2002): Propuesta de correlación entre los sedimentos Pérmicos y Triásicos de la Cordillera Ibérica Este y de las Islas Baleares. *Geogaceta,* 32: 275-278.

Arche, A., López-Gómez, J., Marzo, M., Vargas, H. (2004): The siliciclastic Permian-Triassic deposits in Central and Norhteasten Iberian Peninsula. *Geologica Acta*, 2 (4): 305-320.

Arthaud, F., Matte, F. (1977): Late Paleozoic strike-slip faulting in Southern Europe and Northern Africa: result of a right lateral shear zone between the Appalachians and the Urals. *Geological Society of America Bulletin*, 88: 1305-1320.

Baroni, M., Thiemens, M.H., Delmas, R., Savarino, J. (2007): Mass-independent sulfur isotopic compositions in stratospheric volcanic eruptions. *Science*, 315: 84-87.

Baud, A., Magaritz, M., Holser, W.T. (1989): Permian-Triassic of the Tethys: carbon isotope studies. *Geologische Rundschau*, 78: 649-677.

Becker, L., Poreda, R.J., Hunt, A.G., Bunck, T. E., Rampino, M. (2001): Impact event at the Permian-Triassic boundary: Evidence from extraterrestrial noble gases in fullerenes. *Science*, 291: 1530-1533.

Becker, L., Poreda, R.J., Basu, A.R., Pope, K.O., Harrison, T.M., Nicholson, C., Iasky, R. Bedout (2004): A Possible End-Permian Impact Crater Offshore of Northwestern Australia. *Science*, 304: 1469-1474.

Béthoux, O., Papier, F., Nel, A. (2005): The Triassic radiation of the entomofauna. *Palevol Com. Rend. Acad. Siences Paris,* 4 (6-7): 541-553.

Bittner, A. (1896): *Bemerkungen zur neusten Nomenklatur der alpinen Trias* Selbstverlag des Verfassers. Wien: 4 p.

Broutin, J. (1977): Nouvelles données sur la flore des bassins autunostephaniens des environs de Guadalcanal (Province de Seville, Espagne). *Cuadernos de Geología Ibérica*, 4: 91-98.

Broutin, J., Doubinger, J., Gisbert, J., Satta-Passini, S. (1988): Premieres datations palynologiques dans le facies Buntsandstein des Pyrenees catalanes espagnoles. *Comp. Rend. Acad. des Sciences*, 306: 169-163.

Broutin, J., Chateauneuf, J., Galtier, J., Ronchi, A. (1999): L´Autunien d´Autun reste-t-il une réferénce pour les dépôts continentaux du Permien Inferieur d´Europe? *Geologie de la France*, 2: 17-31.

Calvet, F., Tucker, M. (1995): Triassic Reef-mound complexes (Ladinian, upper Muschelkalk), Catalan Ranges, Spain. In: C. Monty, D. Bosence, P. Bridges, B.Pratt (eds.), *Mud Mounds: origin and evolution.* Special Publication of the International Association of Sedimentologists, 23: 311-333.

Campbell, I.H., Czamanski, G.K., Fedorenko, V.A., Hill, R.I., Stepanov, V. (1992): Synchronism of the Siberian Traps and the Permian-Triassic boundary. *Science*, 258: 1760-1763.

Cassinis, G., Toutin-Mourin, N., Virgili, C. (1995): A General outline of the Permian continental basins in southwestern Europe. In: P. A., Scholle, T. M. Peryt, D.S. Ullmer-Scholle (eds.), *The Permian of Northern Pangea,* Springer-Verlag, II, Berlin, 137-157.

Châteauneuf, J.J., Farjanel, G. (1989): Synthèse géologique des bassins permiens français. *Bureau Recherches Géologiques Minières*, *Mèmoire*, 128: 288 p.

Coode, A.M. (1965): A Note on Oceanic transcurrent faults. *Canadian Journal Earth Science*, 2: 400-401.

Courtillot, V. (1999): *Evolutionary Catastrophes. The Science of Mass Extinction.* Cambridge University Press, Cambridge: 173p.

Courtillot, V.E., Renne, R.P. (2003): On the Ages of Flood Basalt Events. *C. R. Geoscience*, 335: 113-140.

Courtillot, V.E., Renne, R.P., Chenet, A., Fluteau, F. (2004): Consistently improving correlation between ages of flood basalts, and mass extinction and oceanic anoxia events. *32nd International Geological Congress*, Abstract volume, Sessions 302-2, Florence.

Corsetti, F. A., Baud, A., Marenco P. J. Richoz, S. (2005): Summary of Early Triassic carbon isotope records. *Palevol Com. Rend. Acad. Siences Paris,* 4 (6-7): 405-418.

Dalloni, M. (1938): Sur les dêpots permiens des Pyrénées à flore de l' Angaride. *Com. Rendus Acad. Siences Paris,* 206: 115-117.

Dalloni, M. (1913): Stratigraphie et tectonique de la region des Nogueras (Pyrénées Centrales) *Bull. Soc. Geol. France,* 4 (13): 243-263.

Davies, F.G. (1999): *Dynamic Earth: Plates, Plumes and Mantle Convection*. Cambridge University Press, Cambridge, 458 p.

Deroin, J.P., Bonin, B. (2003): Late variscan tectonomagmatic activity in Western Europe and surrounding areas: the Mid-Permian Episode. *Boll. Soc. Geol. It.*, vol. Speciale 2: 169-184.

Dietz, R.S. (1961): Continent and ocean evolution by spreading of the sea floor, *Nature*, 190: 854-857.

Díez, J.B., Grauvogel-Stamm, L., Broutin, J., Ferrer, J., Gisbert, J., Liñán, E. (1996): Première découverte d´une paléoflore anisienne dans le faciès Buntsandstein de la Branche Aragonaise de la Cordillère Ibérique (Espagne). *Comptes Rendus Acad. Sciences*, *Paris,* 323: 341-347.

Doubinger, J., Adloff, M. C., Ramos, A., Sopeña, A., Hernando, S. (1977): Primeros estudios palinológicos en el Pérmico y Triásico del Sistema Ibérico y bordes del Sistema Central. *Revista de Palinología*, 1: 27-33.

Dunbar, C.O. (1940): The type Permian: its classification and correlation. *American Association of Petroleum Geologists Bulletin*, 24, 2: 237-281.

Egger, H., Brückl, E. (2006): Gigantic volcanic eruptions and climatic change in the early Eocene. *Int. J. Earth Sci. (Geol. Rundch.)*, 95: 1065-1070.

Erwin, D. H. (1993): *The great Paleozoic crisis: life and death in the Permian*. Columbia University Press, New York, 327 p.

Falke, H. (1972): *The paleogeography of the continental Permian in Central-West and in part of South Europe*. In: H. Falke (ed.), *Essays on European Lower Permian.* Leiden, 115-117

Gaetani, M., Dercourt, J., Vrielynck, B. (2003): The Peri-Tethys Programme: achievements and results. *Episodes*, 26, 2: 79-93.

Gand, G., Garric, J., Demathieu, G., Ellenberger, P. (2000): La Palichnofaune de vertebres tetrapodes du Permien superieur du bassin de Lodève (Languedoc-France). *Palæo Vertebrata*, 29 (1): 82 p.

Gisbert, J. (1984): Les molasses post-hercyniennes dans le Haut Urgell et la Cerdagne occidentale (Pyrenees Catalanes, Espagne). *Comptes Rendus Acádemie des Sciences Paris*, 298: 883-888.

Glenister, B. F., Boyd, D. W., Furnish, W. M. (1992): The Guadalupian: proposed international standard for a middle Permian series. *International Geology Review*, 34 (9): 875-888.

Glikson, G. (2005): Asteroid/comet impact clusters, flood basalts and mass extinctions: Significance of isotopic age overlaps. *Earth and Planetary Science Letters*, 236: 933-937

Gradstein, F., Ogg, J., Smith, A. (eds.) (2004): *A Geological Time Scale 2004.* Cambridge University Press, Cambridge, 589 p.

Grauvogel-Stamm, L., Ash, S.R. (2005): Recovery of the Triasic land flora from the end-Permian life crisis. *Palevol Com. Rend. Acad. Siences Paris ,* 4 (6-7): 525-540.

Gruszczynski, M. Hoffman, A., Malkowski, K., Veizer, J. (1992): Seawater strontium isotopic perturbation at the Permian-Triassic boundary, west Spitsbergen, and its implications of strontium isotopic data. *Geology*, 20: 779-782.

Hallam, A., Wignall, P. B. (1997): *Mass Extinctions and Their Aftermath*. Oxford University Press, Oxford, 320 p.

Hallam, A. (1989): The case for sea-level change as a dominant causal factor in mass extinctions of marine invertebrates. *Philosophical Transactions of the Royal Society*, Ser B 325: 437-455.

Hancox, J.P., Brandt, D., Reimold, W.U., Koeberl, C., Neveling, J. (2002): Permian-Triassic boundary in the northwest Karoo basin: Current stratigraphic placement, implications for basin development models, and the search for evidence of impact. *Geological Society of America*, Special Paper, 356: 429-444.

Heezen, B.C., (1960): The rift in the ocean floor. *Scientific American*, 203: 98-110.

Henderson, M. C. (2005): International Correlation of the Marine Permian Time Scale. *Permophiles,* 46: 6-9.

Hernando, S., Schott, J-J., Thuizat, R., Montigny, R. (1980): Age des andesites et des sediments interstratifiés de la région d´Atienza (Espagne): étude stratigraphique, géochronologique et paleomagnétique. *Sciences Géologiques Bulletin*, 33, 2: 119-128.

Holser, W.T. (1984): Gradual and abrupt Shifts in Ocean Chemistry during Phanerozoic time. In: H. D. Holland, A. F. Trendall (eds.), *Patterns of Change in Earth Evolution*. Springer Verlag, Berlin: 123-143.

Holser, W.T., Magaritz, M., Wright, J. (1986): Chemical and isotopic variations in the world ocean during Phanerozoic time. In: O. Walliser (ed.), *Global Bio-events*. Springer Verlag, Berlin, 63-74.

Irving, E. (1959): Paleomagnetic pole positions. *Geophys. J.R. Astron. Soc.,* 2: 51-77.

Jones, A.P., Price, D.G., DeCarli, P., Price, N., Hayhurst, C. (2001): Modelling impact decompression melting: a possible trigger for impact induced volcanism and mantle hotspots? In: *Impact Markers in the Stratigraphic record*. 6th ESF-IMPACT Workshop, Granada, 57-58.

Kaiho, K., Kajiwara, Y., Nakano, T., Miura, Y., Kawahata, H., Tazaki, K. Ueshima, M., Chen, Z., Shi, R.G. (2001): End-Permian catastrophe by a bolide impact: Evidence of a gigantic release of sulfur from the mantle. *Geological Society of America*. *Geology*, 29, 9: 815-818.

Kirchner, J.W., Weil, A. (2005): Fossils make waves. *Nature,* 434: 147-148.

Koeberl, C., Gilmour, I., Reimold, W.U., C Claeys, P., Ivanov, B. (2002): End-Permian catastrophe by bolide impact: Evidence of a gigantic release of sulfur from the mantle: Comment and Reply. *Geology*, 30, 9: 855-856.

Lago, M., Arranz, E., Procoví, A., Galé, C., Gil-Imaz, A. (2004a): Permian magmatism and basin dynamics in the southern Pyrenees: a record of the transition from late Variscan transtension to early Alpine extension. In: *Permo-Carboniferous Magmatism and Rifting in Europe.* Geol. Soc. Spec. Publ*.,* 223, London, 430-464.

Lago, M., Arranz, E., Procoví, A., Galé, C., Gil-Imaz, A. (2004b): Lower Permian magmatism of the Iberian Chain, Central Spain, and its relationships to extensional tectonics. In: *Permo-Carboniferous Magmatism and Rifting in Europe.* Geol. Soc. Spec. Publ., 223, London: 465-490.

Lago, M., Gil, A., Arranz, E., Galé, C., Pocoví, A. (2005): Magmatism in the intracratonic Central Iberian basins during the Permian: Palaeoenvironmental consequences. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 229: 83-103

Lambeck, K., Tezer, M., Potter E. (2002): Links between climate and sea levels for the past three million years*. Nature*, 419: 199-206.

López-Gómez, J., Arche, A., Calvet, F., Goy, A. (1998): Epicontinenntal marine carbonate sediments of the Middle and Upper Triassic in the westernmost part of the Tethys Sea, Iberian Peninsula. *Zbl. Geol. Paläontol*., 1: 1033-1084.

López-Gómez, J., Arche, A., Pérez-López, A. (2002): Permian and Triassic. In: W. Gibbons, T. Montero (eds.), *Geology of Spain.* Geol. Soc. Sp. Pub. London: 185-212.

López-Gómez, J., Arche, A., Marzo, M., Durand, M. (2005): Stratigraphical and paleogeographical significance of the continental sedimentary transition across the Permian-Triassic boundary in Spain. *Paleogeography, Palaeoclimatology, Palaeoecology,* 229: 3-23.

Lovelock, J.E. (1979): *Gaia, A new look at Life on Earth.* Oxford University Press, New York, 157 p.

Lucas, C., Gisbert, J. (1995): Carbonifère Superieur et Permien. In: A. Barnolas, J. C. Chiron (eds.), *Synthese geologique et geophysique des Pyrenees*, BRGM, 1, Orleans, 339-359.

Martin, E., Macdougall, J. D. (1995): Sr and Nd isotopes at the Permian/Triassic boundary: a record of climate change. *Chemical Geology*, 125: 73-100.

Martínez García, E., Luque, C., Burkhardt, R., Gutierrez Claverol, M. (1994): Primer descubrimiento de huellas de tetrápodos, invertebrados y plantas en el Pérmico de la Cordillera Cantábrica (Peña Sagra, Cantábria). Proceedings. *III Coloquio de Estratigrafía y Paleogeografía del Pérmico y Triásico de España*, Cuenca, 77-78.

Mei, S. (1996): The Best Natural Boundary: a New Concept Developed by Combining the Sequence Boundary with the GSSP. *Acta Geologica Sinica*, 9, 1: 98-106.

Melosh, H.J. (2001): Impact induced volcanism: A geological myth. *Geological Society of America Abstracts with Programs*, 33, 7: A-433.

Montañez, I. P., Tabor, N.J., Niemeier, D., DiMichele, W.A., Frank, T.D., Fielding, C.R., Isbell, J.L., Birgenheier, L.P., Rygel, M.C. (2007): CO_2-forced climate and vegetation instability during Late Paleozoic Deglaciation. *Science*, 315: 87-91.

Müllerv, A., Goncharo, R.D., Kritski, A. (2005): Geophysical evaluation of the enigmatic Bedout basement high, offshore northwestern Australia. *Earth and Planetary Science Letters*, 237: 264-284.

Munier-Chalmas, E., Lapparent, A. (1893): Note sur la nomenclature des terrains sédimentaires. *Bull. Soc. Géol. France*, 3s, 21: 438-488.

Murchison, R.I., De Verneuil, E., von Kayserling, A. (1845): *The geology of Russia in Europe and the Ural Mountains*. In: John Murray, London, T I, Geology, XXIV, 700 p., T II, Paleontology , XXXII, 512 p.

Olsen, P.E. (1999): Giant Lava Flows, Mass Extinctions and Mantle Plumes*. Science*, 284: 604-605.

Pagani, M., Caldeira,K., Archer, D., Zachos, C. (2006): An ancient carbon mystery. *Science*, 314: 1556-1557.

Patac, I. (1920): *La formación uraliense asturiana. Estudios de cuencas carboníferas*. Compañía Asturiana de Artes Gráficas, 50 p.

Payne, J.L., Lehrmann, D.J., Wei, J., Orchard, M.J., Schrag, D.P., Knoll, A.H. (2004): Large Perturbations of the Carbon Cycle During Recovery from the End-Permian Extinction*. Science*, 305: 506-509.

Phipps-Morgan, J., Reston, T.J., Ranero, C. R. (2004): Contemporaneous mass extinction, continental flood basalts and impacts signals: are mantle plume induced lithospheric gas explosions the causal link ? *Earth and Planetary Science Letters*, 217: 263-284.

Phipps-Morgan, J., Reston, T.J., Ranero, C. R. (2005): Reply to A. Glikson´scomment on « Contemporaneous mass extinctions, continental flood basalts, and « impacts signals »: Are mantle plume-induced lithospheric gas explosions the casual link ? *Earth and Planetary Science Letters*, 236: 938-941.

Pruvost, P. (1956): *Lexique stratigraphique international*. *Europe*, 1 (4-11): 197-198.

Ramos, A., Doubinger, J. (1979): Découverte d'une microflore thuringienne dans le Buntsandstein de la Cordillère Ibèrique (Espagne). *Comp. Rend. Acad. Sciences,* 289: 525-529.

Ramos, A., Doubinger, J. (1989): Permian datations dans le facies Buntsandstein de Majorque. *Com. Rend. Acad. Siences*, 309: 1089-1094.

Raup, D.M., Sepkoski, J.J., Jr. (1982): Mass extinction in the marine fossil record. *Science*, 215: 1501-1503.

Retallack, G.C., Smith, R.M.H., Ward, D.P. (2003): Vertebrate extinction across Permian–Triassic boundary in Karoo Basin, South Africa. *Society American Bulletin,* 115, 9: 1133-1152.

Renevier, E. (1874): Tableau des terrains sédimentaires formés pendant les époques de la phase organique du globe terrestre. *Bull. De la Soc. Vavdoise des Science Naturelles. Lausane*, 12: 218-252.

Riba, O. (1959): Estudio geológico de la Sierra de Albarracín. Pub. Instituto Lucas Mallada, CSIC, 16: 238p

Rohde, R.A., Muller, R.A. (2005): Cycles in fossil diversity. *Nature*, 434: 208-210.

Rosell, J., Arribas, J., Elizaga, E., Gómez, D. (1988): Caracterización sedimentológica y petrográfica de la serie roja permo-triásica de la isla de Menorca. *Boletín Geológico y Minero*, T XCIX: 71-82.

Rothwell, G.W., Grauvogel-Stamm, L., Mapes, G. (2000): An herbaceous fossil conifer. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 156: 139-145.

Runcorn, S.K. (1959): Rock Magnetism. *Science*, 129: 1002-1011.

Schneider, J.W., Rössler, R., Gaitzsch, B. (1994): Time lines of the Late Variscan volcanism, a holostratigraphic synthesis. *Zbl. Geol. Palaont*., 1: 477-490.

Scotese, C.R., Langford, R.P. (1995): Pangea and the Paleogeography of the Permian. In: Scholle, P.A., Peryt, T.M., Ulmer-Scholle, D.S. (eds.) *The Permian of Northern Pangea.* Paleogeography, Paleoclimates, Stratigraphy 1. Springer Verlag, Berlin, 3-19.

Sephton, A.M., Veefkind, R. J., Looy, V. C., Visscher H., Brinkhuis H., de Leeuw, J. W. (2002): Lateral Variations in End-Permian Organic Matter in Northern Italy. In: E. Buffetaut, C., Koeberl (eds.), *Geological and Biological Effects of Impact Events*. 11- 24. Springer.

Sephton, A.M., Looy, V. C., Brinkhuis H., Wignall, B. P., Visscher H. (2005): Catastrophic soil erosion during the end-Permian biotic crisis. *Geological Society of America,* 33, 12: 941-944.

Sepkoski, J.J., Jr. (1991): A Model of onshore-offshore change in faunal diversity. *Paleobiology*, 17: 58-77.

Sepkoski, J. J., Jr., Raup, D. M. (1986): Periodicity in marine extinction events. In: D. K. Elliot (ed.), *Dynamics of extinction*, Wiley, New York: 3-36.

Sidor, C.A., O'Keefe, F.R., Damiani, R., Steyer, J.S., Smith, R.M.H., Larsson, H.C.E., Sereno, P.C., IDE, O., Maga, A. (2005): Permian tetrapods from the Sahara show climate-controlled endemism in Pangaea. *Nature*, 434: 886-889.

Smith, R.M.H. (1995): Changing fluvial environments across the Permian-Triassic boundary in the Karoo Basin, South Africa and possible causes of tetrapod extinctions. *Paleogeography, Palaeoclimatology, Palaeoecology*, 117: 81-104.

Smith, R., Botha, J. (2005): The recovery of terrestrial vertebrate diversity in South Africa Karoo Basin after the end-Permian extinction. *Palevol Com. Rend. Acad. Siences Paris,* 4 (6-7): 555-568.

Sopeña, A. (2004): Cordillera Ibérica y Costero Catalana. In: J. A. Vera (ed.), *Geología de España.* S.G.E.- Instituto Geológico Minero España, Madrid, 587- 634.

Sopeña, A., Virgili, C., Ramos, A., Hernando, S. (1977): Pérmico continental en España. *Cuadernos Geología Ibérica*, 4: 11-34.

Stampfli, G.M., Borel, G.D. (2002): A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons. *Earth and Planetary Science Letters*, 196: 17-33.

Stampfli, G.M., Borel, G.D., Cavazza, W., Mosar, J., Ziegler, P.A. (2001): *The Paleotectonic Atlas of the PeriTethyan Domain.* European Geophysical Society. CD-ROM.

Steiner, M., Eshet, Y., Rampino, R.M., Schwindt, M.D. (2001): Simultaneous terrestrial and marine mass extinctions at the Permian-Triassic boundary: Discovery of the global fungal spike in rocks of the Karoo Supergroup (South Africa). In: *Impact Markers in the Stratigraphic record*. 6th ESF-IMPACT Workshop, Granada, 121-122.

Stepanov, D.L. (1973): The Permian System in the U.S.S.R. In: A. Logan, L. V., Hills (eds.), *The Permian and Triassic systems and their mutual boundary.* Canadian Society of Petroleum Geologists Memoir, 2: 120-136.

Stille, H. (1924): Grundfragen der Vergleixen Tectonic. Geb. Borntraeger. Berlin. 443p.

Tozer, E.T. (1984): *The Trias and its Ammonoids: Evolution of a Time Scale.* Geological Society of Canada Miscellaneous Report, 35: 171p.

Tozer, E.T. (1988): Towards a definition of the Permian-Triassic Boundary. *Episodes*, 11: 251-255.

Virgili, C. (1958): *El Triàsico de los Catalànides*. Instituto Geológico y Minero de España, 69: 856 p.

Virgili, C. (1987): Problemática del Trías y Pérmico Superior del Bloque Ibérico. *Cuadernos Geología Ibérica*, 11: XXXIX-LII.

Virgili, C. (1989): Permian subdivision in the Iberian Microplate (Western Tethys). *XIe Congrès International de Stratigraphie et de Géologie du carbonifére Beijing 1987*, Compte Rendu 2, Nanjing, China, 277-285.

Virgili, C. (2001): La chronostratigraphie du Permien et les series continentales de l'Europe Occidentale. In: *Crise Permienne*, 16ª Journee Thematique de l'AGP, 15, Résumés. Paris, 5-6.

Virgili, C. (2003): *El fin de los mitos geológicos. Lyell*. Colección Científicos para la Historia 13. Nivola libros y ediciones, Tres Cantos, 318 p.

Virgili, C. (2006): *Una gran crisi climàtica i Biològica: Anàlisi i Reflexions.* Mem. Real Acadèmia Ciències i Arts de Barcelona, 1.002, 62, 6: 304 p.

Virgili, C., Hernándo, S., Ramos, A., Sopeña, A. (1973): La sédimentación permienne au centre de l'Espagne. *C.R. S. Société Geolóque de France*, T. XV, 5-6: 109-111. Paris.

Virgili, C., Hernando, S., Ramos, A., Sopeña, A. (1976): Spain. In: H. Falke (ed.), *The Continental Permian in Central, West, and South Europe*. Leiden, 91-109.

Virgili, C., Sopeña, A., Ramos, A., Hernando, S. (1977): Problemas de la Cronoestratigrafía del Trias en España. *Cuadernos Geología Ibérica*, 4: 57-88.

Virgili, C., Cassinis, G., Broutin, J. (2001): Permian to Triassic sequences and events from selected continental areas of south-western Europe. In: *Intern. Field Conf. on the Stratigraphic and structural evolution on the Late Carboniferous to Triassic continental and marine successions in Tuscany (Italy).* Siena, Abstract volume, 69-70.

Virgili, C., Cassinis, G., Broutin, J. (2006): Permian to Triassic sequences from selected continental areas of southwestern Europe. In: S.G. Lucas, G. Cassinis and J.W. Schneider (eds.), *Non-Marine Permian Biostratigraphy and Biochronology*. Geological Society Special Publication 265: 231-260.

Ward, P.D., Montgomery, D.R., Smith, R. (2000): Altered River Morphology in South Africa Related to the Permian-Triassic Extinction. *Science,* 289: 1740-1743.

Wegener, A. (1922): *Die Entstelung der Kontinente und Ozeane.* Vieweg and Sons, Braunschweig.

Wilson, J.T. (1976): *Continents Adrift and Continents Aground*. Freeman and Company, San Francisco, 230 p.

Wilson, J.T. (1963): Evidence from Islands on the Spreading of the Ocean Floor. *Nature,* 197: 536-538.

Woods, A.D. (2005): Paleoceanographic and paleoclimatic context of Early Triassic time. *Palevol Com. Rend. Acad. Siences Paris,* 4 (6-7): 395-404.

Xu, G., Grant, R.E. (1994): Brachiopods Near the Permian-Triassic Boundary in South China. Smithsonian Institution Press, Washington, *Smithsonian Contribution to Paleobiology*, 76: 68 p.

Yakubchuk, A., Nikishin, A. (2003): Noril'sk-Talnakh Cu-Ni-PGE deposits: a revised tectonic Model. *Mineralium Deposita*, 39, 2: 125-142.

Yang, Z., Yin, H., Wu, S. F. (1984): Permo-Triassic Boundary and biostratigraphic zonation of South China. *Academic sessions of the Paleontological Society of China*, Selected Papers 13, 14: 99-110.

Yang, Z., Yin, H. (1987): Achievements in the study of Permo-Triassic events in South China. *Advances in Sciences of China*, 2: 23-43.

Yang, Z., Sheng, J., Yin, H. (1995): The Permian-Triassic boundary: the global stratotype section and point (GSSP). *Episodes*, 18 (1-2): 49-53.

Yin, H., Huang, S., Zhang, K., Yang, F. (1989): Volcanism at the Permian-Triassic boundary in South China and its effects on mass extinctions. *Acta Geologica Sinica*, 2, 4: 417-431.

Yin, H., Zhang, K., Tong, J., Yang, Z., Wu, S. (2001): The Global Stratotype and Point of the Permian-Triassic Boundary. *Episodes,* 24, 2: 102-114.