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

Journal of Iberian Geology 34 (1) 2008: 29-56

Journal of Iberian Geology
AN INTERNATIONAL PUBLICATION OF EARTH SCIENCES

The playa environments of the Lodève Permian basin (Languedoc-France)

Los ambientes de playa de la Cuenca de Lòdeve (Languedoc-Francia)

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Received: 13/05/07/ Accepted: 25/09/07

Abstract

The Lodève Permian synrift sequence is represented by thick stacked climate-controled playa cycles which have been constrained by structural, sedimentological, geochemical and paleontological processes. The present paper merges the different results in order to better constrain the dynamics and palaeoecologycal evolution of the playa system from Late Cisuralian to Early Lopingian time. In this depositional environment, thining upwards sheet-flood sequences represent flooding events; they are relayed by ephemeral ponding, suspension settling and limited carbonate precipitation accompanied by large amounts of shallow to subaerial sedimentary structures (current and wind ripples, desiccation cracks, rain drops, etc.). The aridity of the climate contrasts with the surprising abundance of the fauna encountered into carbonate-rich silty-clay playa-lake deposits. Ephemeral pools are colonized by numerous shellfish: Choncostraca, Triopsids, and Insects, which led to intense burrowing of the overbank deposits (*Scoyenia facies*). Tetrapods are common and dominated by several types of reptiles after footprints: Pelycosauria, Parareptilia and Lepidosauria in the Rabejac Fm, and Mammalian reptiles (Therapsida) on the top of the fluvial deposits of the Salagou Fm near La Lieude farm. In addition, elements of a weighty herbivorous Pelycosaurian and a small amphibian Tupilakosaurid, only described in the Triassic before, have been also found in the Upper part of the Permian series of this sector.

Keywords: Permian, Playa, Triopsids, Conchostraca, Vertebrates, *Scoyenia* ichnofacies, footprints.

Resumen

El ciclo sedimentario sinrift del Pérmico de la cuenca de Lodève (Formaciones Rabéjac y Salagou) está representado por depósitos cíclicos de playa que resultan de factores estrucrurales, sedimentológicos, geoquímicos y biológicos. En este trabajo se exponen evidencias que permiten perfilar la evolución dinámica y palaeoecológica del ambiente de playa entre el Cisuraliense superior y el Lopingiense inferior. En este marco sedimentario se desarrollaron sequencias estratodecrecientes de *sheet-flood* que corresponden a eventos de inundación. Con ellos alternaron episodios con desarollo temporal de charcas efímeras, en las que se generaron sedimentos de grano fino y escasos carbonatos. En estas facies se encuentran estructuras sedimentarias someras a subaéreas (riples de corriente acuáticos y eólicos, grietas de desecación, huellas de gotas de agua, etc.). La aridez general del clima contrasta con la sorprendente abundancia de fauna encontrada, fosilizada en los depósitos finos, ricos en carbonato, de *playa-lake*. Las zonas encharcadas eran colonizadas por pequeños crustáceos: concostráceos, triópsidos e insectos que dejaron sus numerosas huellas de actividad en los depósitos de *overbank* (facies de *Scoyenia*). Los tetrápodos también eran abundantes, y se han reconocido, a partir de sus huellas, diferentes reptiles (Pelycosauria, Parareptilia y Lepidosauria en la Fm. Rabejac, y Therapsida en la parte superior de los depósitos de la Fm. Salagou próximos a la granja de Lieude). Además, se describen elementos atribuibles a un pelicosaurio hervívoro de gran peso, y a un pequeño anfibio tupilakosaurio. Estos últimos eran conocidos solamente en el Triásico, antes de su descubrimiento en la parte superior del Pérmico de la cuenca de Lodève.

Palabras clave: Pérmico, playa, triópsidos, concostráceos, icnofacies de *Scoyenia*, huellas de pisadas.

1. Introduction

Playa sequences represent one of the richest suites of sedimentary facies and fossils stacked in the geological record because of the overall periodic change of the depositional system. This dry flat-floored bottom depression found in inner to coastal basins of arid and semiarid regions are periodically ponded by ephemeral shallow lakes (Blackwelder, 1931) and shows multiple facies changes from alluvial fan gravel and wadi poorly-sorted sand to lacustrine laminated mud with possible evaporite deposits, topped by desiccated surfaces and aeolian sand dunes. A variety of flora and fauna, carefully preserved, in the fine grained sediments of the playa-lakes reveal evidence of life bloom during humid periods. Animal tracks and other biogenic structures (bioturbations, burrows, paleosoils) complete the paleoecological diversity on the wet banks of the channels and standing waters.

The Lodève Permian Basin, in the southern border of the Massif Central, displays a particular well preserved suite of playa sequences and associated paleontological remains, because of both large continuous outcrops and a dense mining network for uranium exploration. In particular, large open mine quarries coupled with more than 40 km of galleries and thousand-km borehole revealed complementary fossiliferous-rich layers which allow to better constrain the structure and the geohistory of the basin.

Plant remains are of particular abundance in the lacustrine blackshales of the lowermost part of the Autunian Group and vanish progressively upwards because of the low potential of preservation in the red playa/floodplain pelites of the Saxonian Group. On the contrary, these red sub-emersive facies present a high potential for vertebrate footprints and ichnotraces preservation, associated locally to invertebrate and plant debris accumulations in flooding rills. Thus, in them, Dr Jean Lapeyrie, surgeon in Lodève discovered, about twenty years ago, an exceptional rich suite of insects, conchostracans and triopsids in several levels, ranging from the base to the top of the Salagou Fm of the Saxonian Group. More recently this Formation revealed vertebrate remains which are excavate every year by a French-German team (Dijon, Freiberg, Montpellier Universities, MNHN and CNRS of Paris; Schleusingen Museum, Thuringe).

These paleontological studies, coupled with sedimentological and structural data help to constrain the overall conditions of the Permian playa paleoenvironment. This paper is an exhaustive synthesis of the physical, biological and geodynamical evolution of the Lodève Permian playa system.

2. General location

The Lodève basin is a half-graben of Permian age, with a 15-20° southward dipping continental infilling that extends over an area of about 150 km^2, on the southern border of the Massif Central (Fig. 1). The basin was sealed by a thick horizontal Mesozoic cover which is presently eroded, allowing the exposure of the basement and of the lower Permian series on the northern border. It is surrounded by the Palaeozoic of the Montagne Noire to the west, the Mesozoic Causses Plateau to the north, and the Languedoc Tertiary plain to the south. The Permian deposits overlap both the Graissessac Stephanian deposits which crop out westward in a narrow basin and folded Cambrian carbonates which are exhumed in the North of the basin (Lodève Ridge, Fig. 2). More precisely, four domains demarcate the basin (Figs. 1, 2):

Northward, the basin is bounded by the plateau of the "Causse du Larzac" (700 m high) formed by a 400 m-thick succession of Mesozoic limestone deposits (Jurassic), by basal sandstone, mudstone and evaporite deposits (Triassic). These latters are subhorizontal and lie unconformably on the Permian and on the hercynian basement, which outcrops directly to the north forming the "Lodève Ridge"; to the south-west in the Montagne Noire, and to the north-east in the Cévennes.

Westward, the basin is hidden by the north-south stretch basaltic plateau of the Escandorgue (800 m high), which underlines a volcanic main axis of Pliocene to Quaternary age.

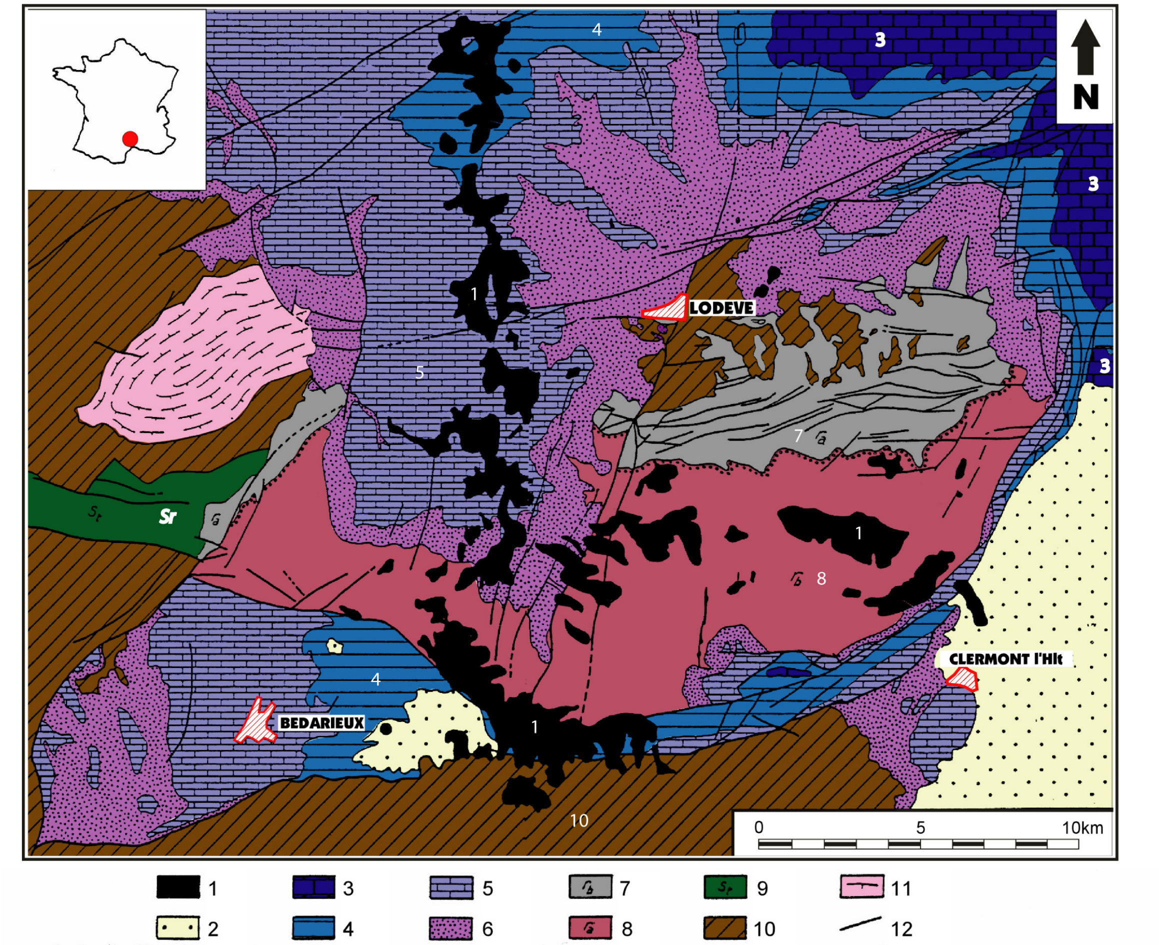


Fig. 1.- Detailed geological map of the Lodève Permian basin. 1: Plio- Quaternary basaltic volcanism, 2: Tertiary to Quaternary deposits, 3: Upper Jurassic, 4: Middle Jurassic, 5: Lower Jurassic, 6: Triassic, 7: Autunian Group: Lower Cisuralian, 8: Saxonian Group: Upper Cisuralian to Lower Lopingian, 9: Gzhelian, 10: Hercynian basement, 11: Granites of Mendic, 12: Faults; from Lopez and Petit (2003), modified.

Fig. 1.- Mapa detallado de la Cuenca pérmica de Lòdeve. 1: Volcanismo basáltico Plio- Cuaternario. 2: Depósitos terciarios-cuaternarios. 3: Jurásico Superior. 4: Jurásico Medio. 5: Jurásico Inferior. 6: Triásico. 7: Grupo Autuniense: Cisuraliense inferior. 8: Grupo Saxoniense: Cisuraliense-Lopingiense inferior. 9: Gzeliense. 10: Basamento hercínico. 11 Granitos de Mendic. 12: Fallas. Modificado de Lopez and Petit (2003).

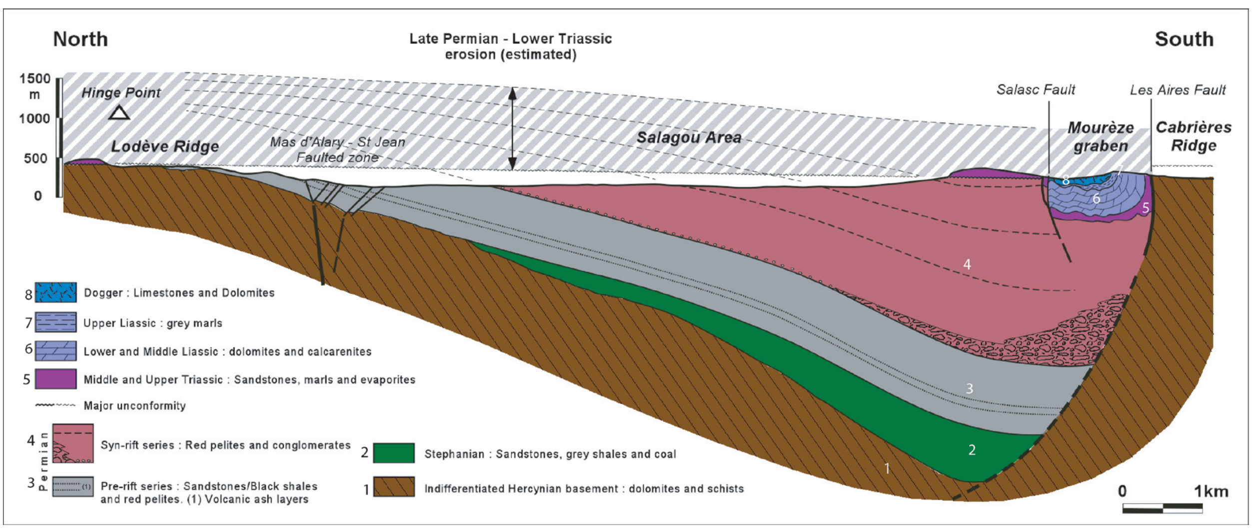


Fig. 2.- N-S-cross-section of the Lodève Permian basin; from Lopez and Petit (2003), modified.

Fig. 2.- Corte estratigráfico N-S de la Cuenca pérmica de Lòdeve. Modificado de Lopez y Petit (2003).

South-westward, the hills of Cabrières (350 m high) represent the eastern extremity of the Montagne Noire hercynian folded belt.

Eastward, the basin is limited by the NNE-SSW trending Cévennes Fault along which a slice of Lower Liassic carbonates (Hettangian) is sandwiched between the Permian and the Cenozoic deposits of the Hérault valley. There is no information of the continuity of the Lodève basin eastward of the Cévennes Fault. The Lergue valley at the "*cluse de Rabieux*" constitutes the main access to the basin, when coming from the south. Beyond the Cévennes fault limit, the Tertiary molasses of the Hérault plain represent the most important wine growing of the region.

Southward, the basin is presently limited by the E-W trending les Aires-Mas Blanc fault. This post-Bathonian down-to-South normal fault precludes observations of the southern border of the basin. Volcanic ashes beds (= "cinérites) correlations between the Lodève and the Gabian basins, located 10 km southward, argue for the connection of both basins during the Lower Permian time. However, the Pre-Anisian tilting of Permian deposits implies that the basin registered a synsedimentary tilting during the Middle/Upper Permian time in relation with the activation of a north-dipping listric fault, south of "les Aires-Mas Blanc fault". The Lower to Middle Jurassic carbonates of the Mourèze graben are characterized by both slide blocks of Lower Liassic carbonates related to Liassic extension and folds, related to later Pyrenean shortening. At a general scale, the crustal extension linked to the Cévennes fault is related to the thinning of the crust, associated to the opening of the Ligurian Ocean during the Early Jurassic time (Lemoine *et al.*, 1984).

3. Origin, palaeontology and stratigraphy of the studied basin

3. 1. Basin geohistory

3. 1. 1. Hercynian cycle

Over a Precambrian basement, the series are mainly composed of shelf deposits (carbonate and siliciclastic facies) in the Montagne Noire and a comprehensive series of slope shales in the Cévennes. During the Lower Carboniferous, the paroxysm of the Hercynian shortening conduced to turbidite deposition in front of large southward vergent recumbent folds, in the southern side of the Montagne Noire.

The shortening stage is followed in the Montagne Noire by the uplift of the gneiss dome in the axial zone, and the associated collapse of the northern border with the opening of the extensional basin of Graissessac during the Wesphalian time (Echtler and Malavieille, 1990). In this E-W elongated basin, a high heat flow was responsible for coalification of many lacustrine coal beds sandwiched in coarse grained fluvial to deltaic deposits (Becq-Giraudon, 1973; Saint-Martin, 1993). Eastward, the E-W trending Graissessac basin is overlaid by the Permian deposits of the Lodève basin (Garric, 1965; 2007). It forms a south dipping half-graben necessary limited to the south by a north dipping listric normal fault related to the late orogenic extension.

3. 1. 2. Mesozoic sedimentation

At the base of the Mesozoic series, the Middle Triassic deposits, unconformably seal a major erosive surface truncating the Permian half-graben and its basement at the western margin of the South-East basin. The siliclastic continental platform of the Triassic (fluvial to playa-lake dominated systems, Lopez and Mader, 1985; Lopez, 1987; Lopez *et al*., 2005) was invaded by a shallow carbonate platform (stromatolithic dolomudstone flat) during the Lower to Middle Liassic time. The later was drowned by pelagic marls at the Upper Liassic time. During this period, the sedimentation was controlled by NE-SW trending faults (in particular the Cévennes fault) with an overall eastward deepening toward the South-East Basin. This crustal scale extension was associated to the thinning of the crust during the opening of the Liguro-Tethysian ocean (Lopez, 1992). Upper Liassic marls grade upward to an outer shelf marl-carbonate interbedding and high energy shelf deposits during Middle Jurassic. Upper Jurassic deposits are dominated by restricted inner to outer carbonate platform sediments (Causses Gulf) (Lopez *et al.,* 1997).

3. 2. Lithostratigraphy

Permian deposits were subdivided for a long time (Feys and Greber, 1972; Châteauneuf and Farjanel, 1989) into 2 large megasequences: Autunian and Saxonian, both lying unconformably upon the Upper Carboniferous and on the Hercynian basement.

In the Lodève basin, the Permian deposits (Fig. 3, 4) have been differently divided in accordance to different authors with slight modifications of the terminology proposed by the Cogema (Uranium General Company) which uses numerous key beds such as ash-layers (cinerites) and organic-rich layers ("faciès couche"), allowing fine correlations. In this sense, two main facies assemblages have been distinguished which represent, both an overall geodynamical and a paleoenvironmental change in the basin geohistory.

In the Lower part of the basin infill the 730 m-thick Pre-rift series (Autunian according to Feys *et al.* (1972) or Upper Autunian to Lower Thuringien according to Odin (1986) = Autunian Group *sensu* Gand *et al.* (1997). It is composed of fluviatile to deltaïc sandstones (Usclas–St Privat Fm = F 1) evolving into anoxic deep lacustrine black shales with a high potential source rock for HC (Tuillières-Loiras Fm = F 2); the later passing upward to sub-emersive floodplain pelites (Viala Fm = F 3).

The Syn-rift Series (about 2000 m thick = Saxonian Group *sensu* Gand *et al.* (1997) is evidenced by a regional unconformity and by an overall southward thickening of the deposits. This series begins with fluviatile coarse conglomerates evolving to sandstone deposits (Rabejac

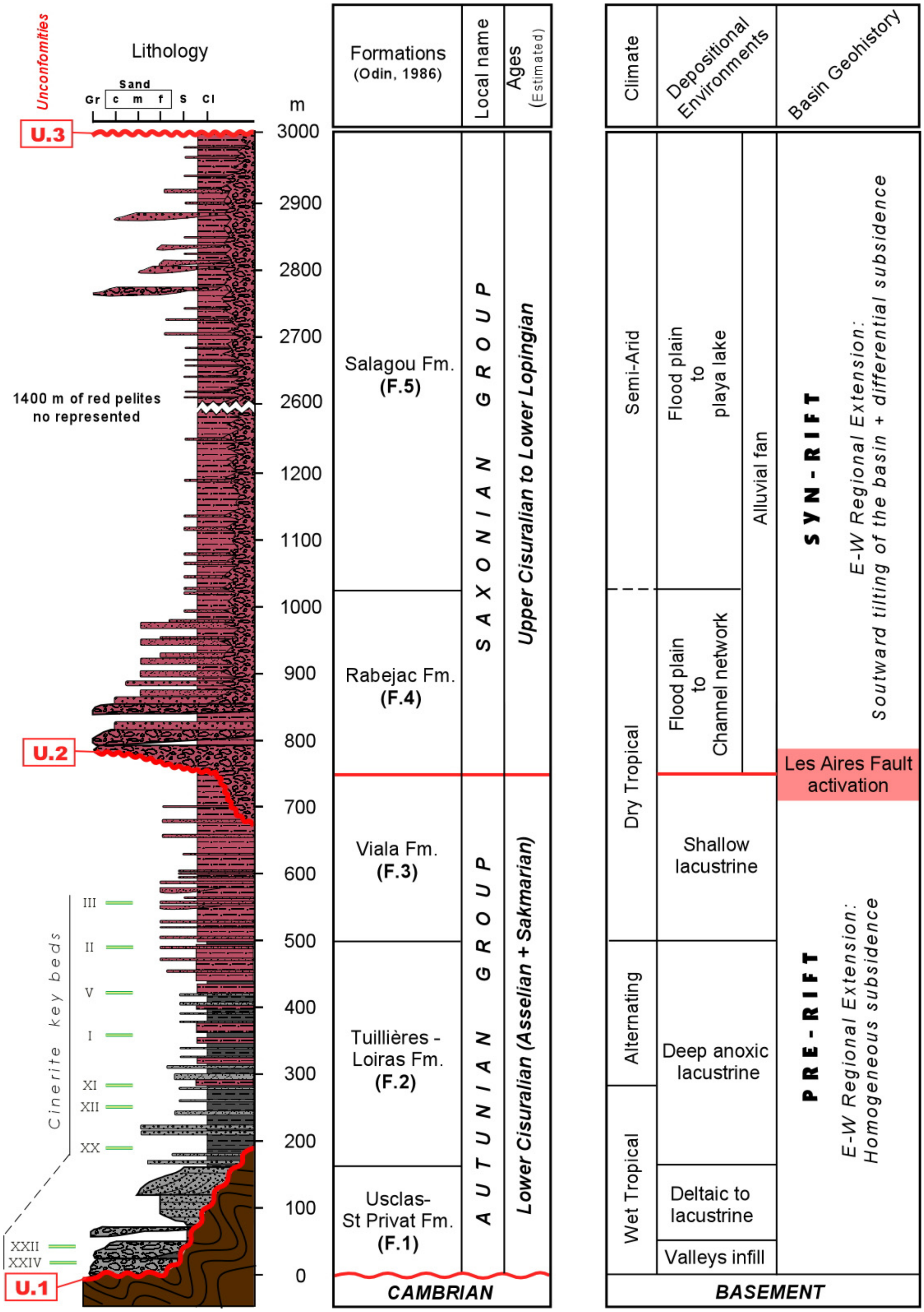
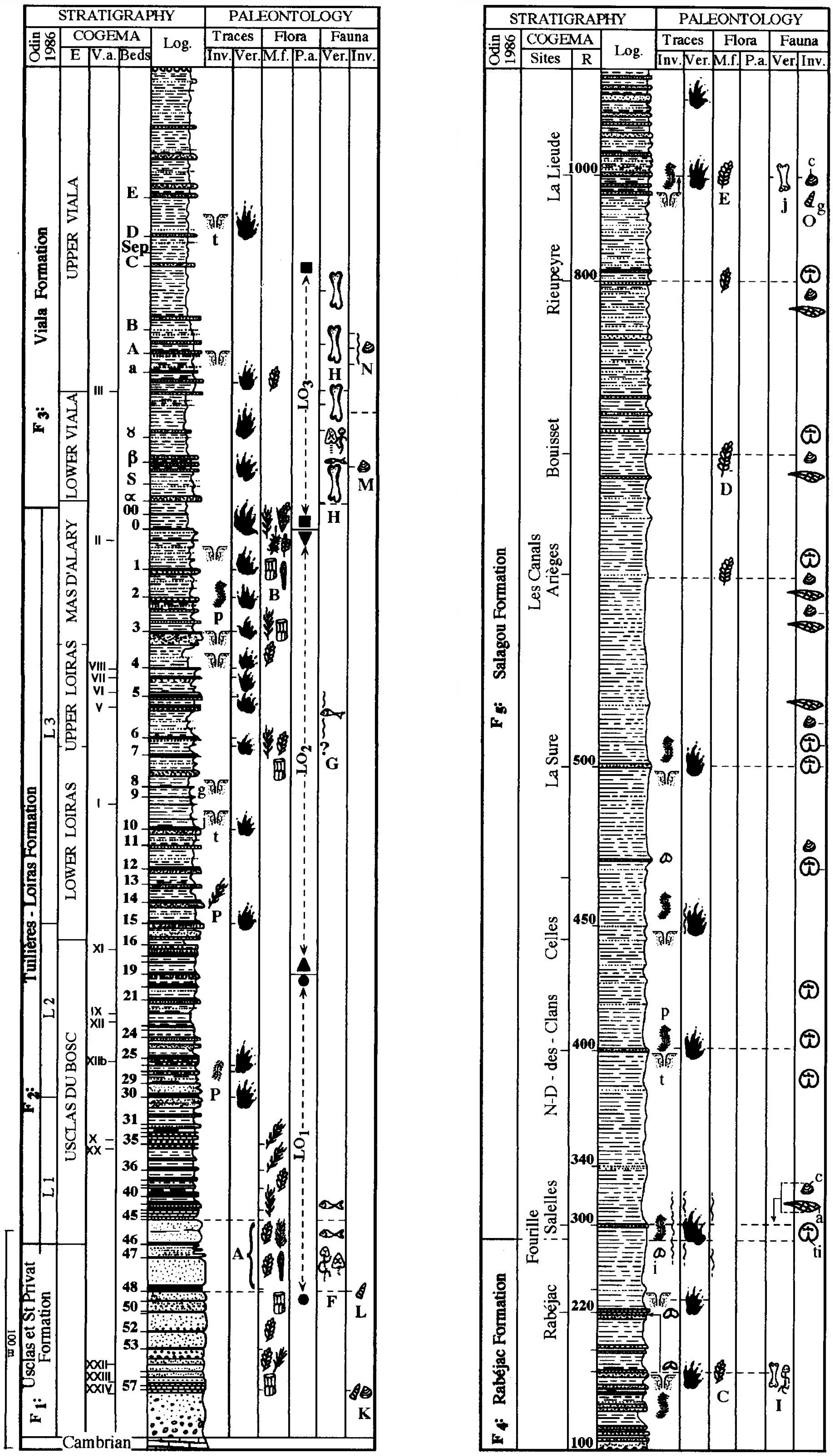


Fig. 3.- General stratigraphy, main lithofacies, palaeoenvironments and geohistory of the Permien deposits of the Lodève Basin; U1, U2, U3 = unconformities, lithology: Gr = conglomerates, sand (c = coarse, m = medium, f = fine), s = siltstone, cl = claystone; m = thickness in metres; Formations = F1-F5; from Lopez and Petit (2003), modified.

Fig. 3.- Estratigrafía general; principales litofacies, paleoambientes y evolución de los depósitos pérmicos de la Cuenca de Lòdeve: U1, U2, U3 = discordancias; Litologías: Gr = conglomerados, areniscas (c = gruesa, m = media, F = fina), s = limo, cl = arcilla; m espesor (en metros); Formaciones = F1-F5; modificado de Lopez and Petit (2003).


STRATIGRAPHY
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Tuilières - Loiras Formation
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Salagou Formation
Rabéjac Formation
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800
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450
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340
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220
100

Fm: F 4) forming a key event into the sedimentary pile. The later evolves rapidly to thick floodplain pelites (= silty red mudstones) and thin playa-lake dolomites (Salagou Fm = F 5). In the western part of the basin, floodplain pelites pass directly to thick debris-flow deposits (La Tour-sur-Orb Member), related to the activity of the bordering faults. The global evolution of the facies is connected to the progressive climatic change from wet-tropical to semi-arid conditions, driven by the gradual northward moving of the continental plate.

3. 3. Palaeontology: flora, fauna and palichnofauna

Connected with the colour of the Formations*,* macro and microflora is mostly present in grey levels of the Autunian: Usclas and St-Privat Fm (= F1), Tuilières-Loiras Fm (= F2). Nevertheless, sometimes in red layers (Rabejac Fm = F4) and especially in green beds of the Salagou Fm, macroflora may be found but is less determinable.

3.3.1. Vertebrates

In the Autunian Group, vertebrates were mentionned, for the first time, during the 19th century. They consist of a skeleton of an Araeoscelidian [*Aphelosaurus lutevensis* (Gervais, 1859) (Thevenin, 1910), redescribed by Falconnet, 2007], some remains of Amphibians ("*Branchiosaurus*", "*Actinodon*", *Discosauriscus, Eryops*), and of Pelycosauria (Heyler, 1969), Fishes with *Acanthodes* sp. (Acanthodians), *Pygopterus* sp. (Palaeonisciforms Actinopterygians) (Heyler, 1969) and *Usclasichthys macrodens* Heyler, 1977. The Saxonian group supplies bone-beds and some amphibians, found in the Rabejac Fm (Heyler 1969) and also a small vertebral column of a Tupilakosaurid (Werneburg *et al*., 2007) coming from the Salagou Fm. A few years ago, Körner discovered in the top of this last Fm, more precisely in la Lieude Member, well preserved Pelycosaurian bones trapped in a debris-flow deposit (under preparation).

In the opposite, *footprints* are rather widespread in all the Formations (Fig. 5) with 3 remarkable sites: the Cogema quarry (Mas d'Alary Member), the Rabejac quarry (Rabejac Fm), and the paleontological slab of "la Lieude" located at the top of the Salagou Fm.

The first observations on footprints were made by F. and P. Ellenberger (1959) then new discoveries and studies were supported by Heyler and Lessertisseur (1963) who described "14 new genera and 16 new "species". Ellenberger (1983-1984) distinguished and erected "almost 130 new ichnotypes". Later, Gand (1987) revised and re-evaluated the French Permian footprints from prospectings in all the French basins and studies of European fossil collections or sites. Thus, he proposed only 14 ichnogenera and 22 ichnospecies for the Lodève basin. Lately, the following list, still has been shortered with 16 ichnosp. (Gand and Durand, 2006) (Fig. 5). They are:

A- Traces attributed to Temnospondyls (Branchiosaurídea and Micromelerpetontidea) = *Anthichnium* (Geinitz, 1861) Haubold, 1971 = *Batrachichnus* (Geinitz, 1861)

Fig. 4.- (opposite page) Detailed stratigraphy and palaeontology of the Permian series, from Gand (1994), modified. Autunian group with F1-F3 Formations, and Saxonian Group with F4, F5 Formations (Odin, 1986); Stratigraphy: Cogema = "Général Company for Uranium Exploitation", E = Members (Laversanne, 1976), V. a = volcanic-ashes indicated by roman numbers, Beds from 57 to 00 with alpha, béta, gamma = bone beds, R = 100-1000 = marker beds; Palaeontology: Traces, Inv. = invertebrates with t = tubes and burrows, p = exogene resting, furrowing, walking/crawling tracks; (i = *Isopodichnus*); Ver. = footprints; compilation from Heyler and Lessertisseur (1963), Laversanne (1976), Ellenberger (1983ab), Gand (1986, 1987, 1990, 1994), Debriette and Gand (1990); Flora, M. f = macroflora, A-E from Cogema (unpublished), Doubinger (1956, 1963), Doubinger and Heyler (1959, 1975), Doubinger and Kruseman (1965), Galtier and Broutin (1995, C, D, E): see Galtier and Broutin, 2008; A 45-48: Tuilières, B: = Mas d'Alary = typical Autunian flora; P. a = palynology, LO1, LO2, LO3 = Doubinger *et al.* (1987) associations; Fauna, Ver = vertebrates, F, G, H, I from Vetter *et al.* (1963), Doubinger and Heyler (1959, 1975), Heyler (1969), Laversanne (1976), Cogema unpublished; F = "*Branchiosaurs*", "*Actinodon"*, *Aphelosaurus*; G = fishes; H = fishes, "*Actinodon*", *Eryops*, pelycosaurian remains; I = "*Actinodon*", J = bone beds from Ellenberger (1983a). Faune Inv.: K-O = numerous Conchostracans levels, K + L, c = gasteropod, Laversanne (1976), Ellenberger (1983a); ti = triopsids, a = insects, Gand *et al.* (1999), Nel *et al.* (1999 a-c), Béthoux *et al*. (2001-2007).

Fig. 4.- (página opuesta) Estratigrafía y paleontología detallada de las series del Pérmico de la Cuenca de Lòdeve. Modificado de Gand (1994). Grupo Autuniense con las Formaciones F1-F3, y Grupo Saxoniense con las Formaciones F4-F5 (Odin, 1986); Estratigrafía: Cogema = "Compañía General para la Explotación de Uranio", E = Miembros (Laversanne, 1976), V. A = cenizas volcánicas indicadas con números romanos, Capas de la 57 a la = con alpha, béta, gamma = niveles con huesos, R = 100-1000 = "capas guía"; Paleontología: Pistas; inv. = invertebrados, con t = tubos y perforaciones, P = diferentes tipos de pistas (indicando descanso, desplazamiento etc..); (i = Isopodichnus); Ver. = impresiones por pisadas; recopilación efectuada por Heyler y Lessertisseur (1963), Laversanne (1976), Ellenberger, (1983a,b), Gand (1986, 1987, 1990, 1994), Debritte y Gand (1990), Flora, M. f = macroflora, A-E de Cogema (no publicado), Doubinger (1956, 1963), Doubinger y Heyler (1959, 1975), Doubinger y Kruseman (1965), Galtier y Broutin (1995), C, D, E: ver Galtier y Broutin en este mismo volumen; A 45-48: Tuilìeres, B: 0 Mas d´Alary = flora típica de Autún; P. A = palinología, LO1, LO2, LO3 = Doubinger and Heyler (1959, 1975), Heyler (1959), Laversanne (1976), Cogema (no publicado); F = "*Brachiosaurus", "Actinodon", Aphelosaurus*; G = peces, H. Peces, "*actinodon*", *Eryops*, restos de pelicosaurio; I = "Actinodon", J = niveles de huesos obtenido de Ellenberger (1983a). Fauna inv.: K-O = numerosos niveles de concostraceos, K + L, c = gasterópodos, Laversanne (1976), Ellenberger (1983a); ti = triopsidos, a = insectos (Gand *et al*., 1999; Nel *et al*., 1999 a-c; Béthoux *et al*., 2001-2007).

Haubold, 1996 with undertracks *Salichnium decessus* or *S. pectinatus* (Heyler and Lessertisseur, 1963); Eryopidea: *Limnopus zeilleri* (Delage, 1912) Gand, 1985; *Amphisauropus latus* Haubold, 1970.

B- Traces ascribable to Amniotes; Captorhinomorpha or gracile reptiles with *Hyloïdichnus major* (Heyler and Lessertisseur, 1963), Haubold, 1971; *Varanopus curvidactylus* Moodie, 1929 (Sarjeant, 1971), *Microsauripus acutipes* Moodie, 1929 (Sarjeant, 1971); *Varanopus rigidus* Gand, 1989; Pelycosauria with *Dimetropus leisnerianus* (Geinitz, 1863) Haubold, 1971, *Dimetropus nicolasi* Gand and Haubold, 1971 being its undertrack; Diadectids (Voigt, 2004): cf. *Ichniotherium cottae* (Pohlig, 1886) Haubold, 1971; "Eosuchia" and Araeoscelids: *Dromopus lacertoides* (Geinitz, 1863) Haubold, 1971; *Dromopus didactylus* (Moodie, 1930) Gand and Haubold, 1984; Therapsida or "Therosauria": *Lunaepes ollierorum*, *Merifontichnus thalerius*, *Planipes brachydactylus* Gand *et al.*, 2000; Caseids or Therapsida: *Brontopus circagiganteus* Gand *et al.,* 2000, *B. giganteus* Heyler and Lessertisseur, 1963.

3.3.2. Invertebrates

Insects, Notostraca, and Conchostraca are also frequent, mostly in the Salagou Formation (see *infra*). Notostraca trackways are described by Gand *et al*. (2008).

3. 4. Stratigraphical data (Fig. 4, 6)

Autunian and Saxonian were regarded a long time as continental stages. The first, of gray colour, was characterised by its flora and microflora suite, and the second, with dominant redbeds deposits was only dated by a "saxonian" footprint association rather similar to that observed in Thuringian Forest (Germany) (Haubold, 1974; Gand, 1987).

The exclusive use of marine stages in the international stratigraphic scale involved *de facto* the abandonment of the terms Autunian and Saxonian and the continental series are nowadays reported to their marine equivalent by radioisotopic data or to references to marine series showing fossiliferous continental intercalations. That is the case for some US American and Russian.

3. 4. 1. Age of the Autunian Group

For the Autunian Group of the Lodève basin, the K/Ar radioisotopic datings, carried out on potassic feldspars of XXIV, X, XI, V volcanic-ashes provided triassic and jurassic ages. Successively, from the base to the top: 242 ±7, 173 ± 5, 206 ± 6, 248 ±8, 248 ±8 Ma, i.e Anisian, Aalenian, Norian, and Olenekian; because of a probable rejuvenation of the K/Ar system during the late tectono-sedimentary events.

From these results, one of us (JS) undertook new datings. Thus, the Viala Fm. is dated of 289.3 +/- 6.7 Ma (U-Pb) (Schneider *et al*., 2006; Röscher and Schneider, 2006). This means an age included in a large interval: Middle Asselian to Middle Artinskian.

From palaeontological data: Zeiller (1898), Florin (1938, 1944), Doubinger (1956, 1963 a, b), Doubinger and Kruseman (1965), Doubinger *et al.* (1987), Galtier and Broutin (1995) (see details *in* Gand *et al*., 2004 a, b) and Broutin *et al.* (1999), the Autunian Group could be dated from the End Gzhelian to the Lower Sakmarian from the top of the Usclas and St-Privat Fm (F1) to the Upper limit of Tuilières-Loiras Fm (F2). This age is supported from autunian flora and microflora. The Viala Fm (F3) would be partly of Artinskian according to the occurrence of *Supaia*.

3. 4. 2. Age of the Saxonian group

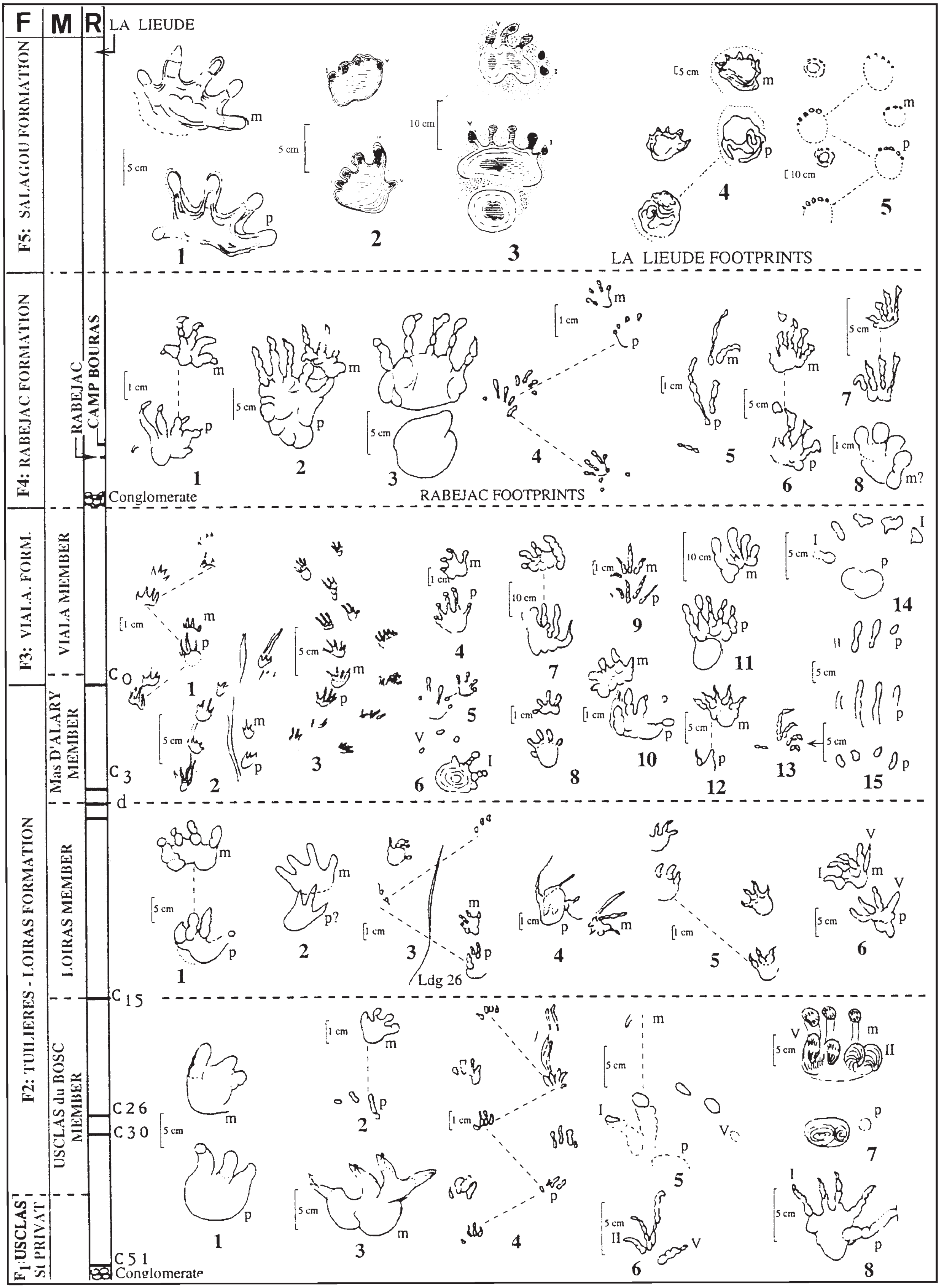
The Octon Member (Fig. 4) would be of 284 ± 4 Ma in age (Schneider *et al*., 2006; Röscher and Schneider, 2006), therefore included between the Middle Sakmarian to the Middle Artinskian interval. From magnetostratigraphic investigations, the "la Lieude Member" would be "in a position just around the Illawara reversal, that is Lower Capitanian respectively Lower Tatarian age" (Legler *et al.,* 2004).

Other ages are suggested by paleontologic data, depending of the taxa. According to:

- The plant *Supaia*, the whole Rabejac Fm (F4) + Salagou Fm (F5) is supposed to represent a part of the Artinskian and the totality of the Kungurian (= Upper Cisuralian).

Fig. 5.- (opposite page) Permian footprints in the Lodève basin from Gand *et al.,* 2004a, F = Formations, M = Members, R = reper beds; Salagou Fm: 1 = *Merifontichnus thalerius*, 2 = *Lunaepes ollierorum*, 3 = *Planipes brachydactylus*, 4 = *Brontopus giganteus*, 5 = *B. circagiganteus*; Rabejac Fm: 1 = *Varanopus curvidactylus*, 2 and 3 = *Dimetropus leisnerianus*; 4 = *Batrachichnus salamandroides*, 5 = *Dromopus didactylus*, 6 and 7 = *Hyloidichnus major*; 8 = *Limnopus* sp.; Viala Fm and Mas d'Alary Member: 1 and 2 = *Salichnium decessus*, 3 = *Salichnium pectinatus*, 4 and 5 = *Batrachichnus salamandroides*, 6 and 7 = *Limnopus zeilleri*, 8 = *Limnopus regularis*, 9 = *Varanopus rigidus*, 10 = *Amphisauropus latus*, 11 = *Dimetropus leisnerianus*, 12 = *D. nicolasi*, 13 = *Dromopus lacertoides*, 14 and 15 = cf *Ichniotherium*; Loiras Member: 1 and 2 = *L. zeilleri*, 3 and 5 = *B. salamandroides*, 4 = *D. lacertoides*, *6 = D. nicolasi*; Formations F1 and F2, Usclas du Bosc Member: 1 and 3 = *Limnopus zeilleri*, 2 and 4 = *B. salamandroides*, 5 and 7 = cf *Ichniotherium*, 6 = *Dromopus lacertoides*, 8 = *Dimetropus nicolasi*.

Fig. 5.- (página opuesta) Pisadas en el pérmico de la Cuenca de Lódeve obtenidas de Gand *et al*. (2004a): Ver nombres en la versión en inglés.


F
M
R
LA LIEUDE
F5: SALAGOU FORMATION
LA LIEUDE FOOTPRINTS
F4: RABEJAC FORMATION
RABEJAC
CAMP BOURAS
Conglomerate
RABEJAC FOOTPRINTS
F3: VIALA. FORM.
VIALA MEMBER
Mas D'ALARY MEMBER
C 0
C 3
d
F2: TUILIERES - LOIRAS FORMATION
LOIRAS MEMBER
Ldg 26
C 15
USCLAS du BOSC MEMBER
C 26
C 30
F1 USCLAS St PRIVAT
C 51
Conglomerate

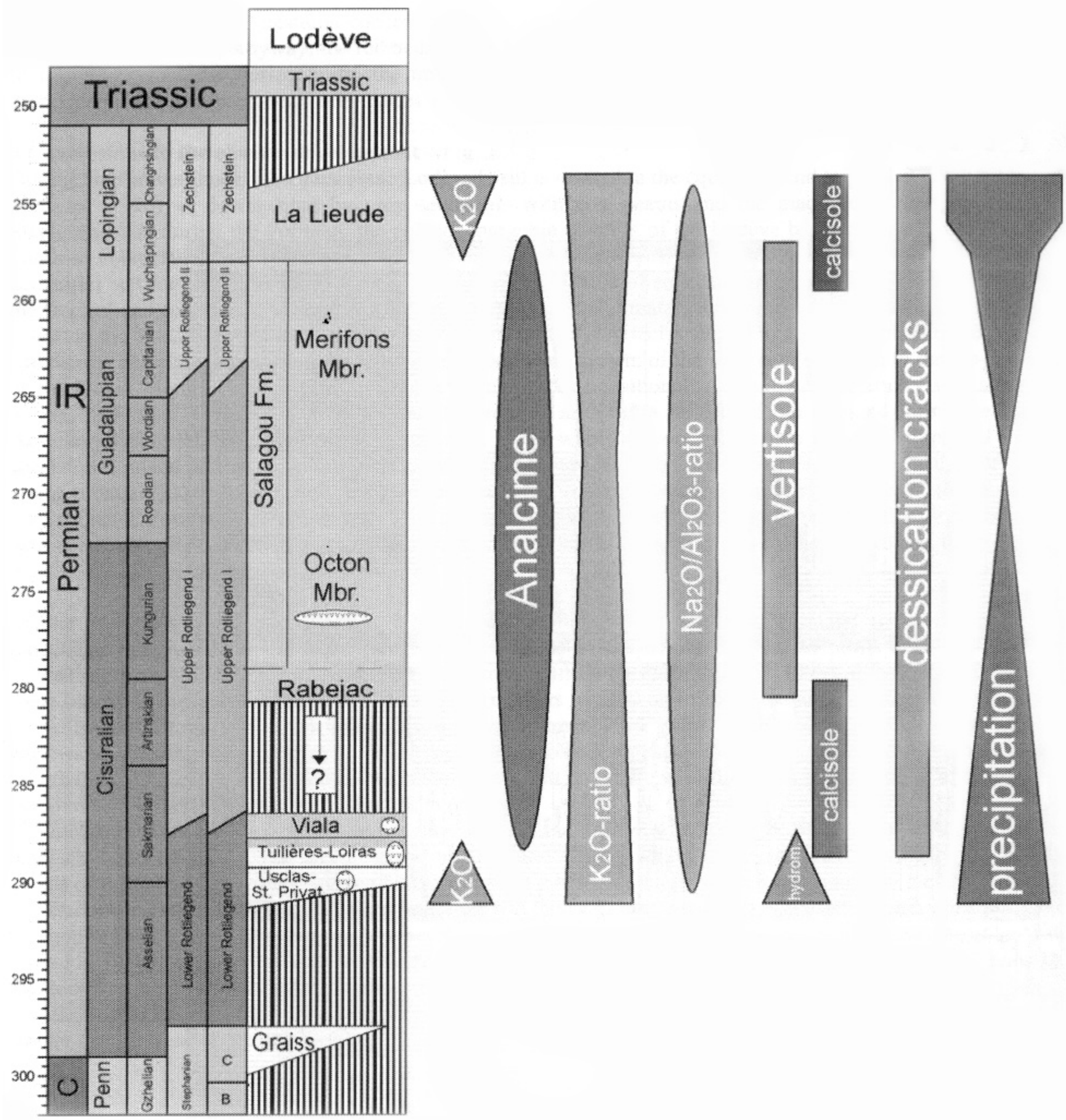


Fig. 6.- Geochemical and Chronostratigraphical data of the Lodève Permian basin serie; Körner and Schneider *in* Legler *et al*. (2004); IR = Illawara reversal.

Fig. 6.- Datos geoquímicos y cronoestratigráficos de la serie de la Cuenca pérmica de Lódeve: Corner y Scheneider *en* Legler *et al*. (2004); IR = el reverso de Illawarra.

- Conchostracans, F4 and F5 would be deposited between the Upper Sakmarian or Artinskian (Middle Cisuralian) to the Tatarian (Capitanian).
- Footprints, the Rabejac Fm + the Salagou Fm (till the "la Lieude") would be dated between the Late Sakmarian (Middle Cisuralian) to the Lower Guadalupian (= Wordian/Roadien) (Gand and Durand, 2006).
- Blattoids, the Salagou Fm (from the base to the Arièges level) would be comprised between the Kungurian (Late Cisuralian) to the Lower Lopingian (Schneider *in* Gand *et al*., 2004a, b).
- Odonatoptera and Archaeorthoptera, the Salagou Fm, between R 300-R 800 the reper levels, could be dated between the Artinskian (Middle Cisuralian) to the Kazanian (Guadalupian) (Nel *et al.*, 1999a-c; Béthoux, 2003).

4. The playa systems of the Saxonian Group (syn-rift series)

During the deposition of the Saxonian Group, the intense activity of the southern bordering fault linked with differential subsidence, and coupled with semi-arid climatic conditions, was periodically compensated by large flooding inputs from the western source areas, leading to a large terminal sub-emersive muddy fan. Under these conditions, the basin acted as a flat-floored bottom depression, periodically ponded by ephemeral shallow lakes during a water-table rise or during direct flooding allowing playa development.

4. 1. The Rabejac Fm: an alluvail fan conglomerate system

The Rabejac Fm overlies the Viala Fm with an angular unconformity clearly visible along the road from Salelles to Loiras village (Fig. 7 A, B), where the mud-supported conglomerates and unsorted coarse sandstones of the Rabejac Fm erode the floodplain pelites of the Viala Fm. This regional unconformity, with a preserved thickness of the Viala Fm, from 50 m near Lunas village in the western part of the basin, to 330 m near St-Jean-de-la-Blaquière in the east, marks the beginning of the activity of the Mas Blanc, les Aires, Cévennes bordering faults with the half graben differentiation of the Lodève basin.

This increasing tectonic activity at the southern and the eastern borders was accompanied by a sudden uplift of the hercynian ranges in the western limit of the basin (Montagne Noire domain) with an overall progradation of alluvial fan systems and debris-flows at the base of the Rabejac Fm.

The Rabejac Fm (= F4) was subdivided, from the western to the eastern part of the basin by Odin (1986), successively in the St-Xist, Rabejac and Lafont "facies". This Formation starts with fluvial basal conglomerates erosive on the Viala Fm. They extend on the entire basin but are thicker and coarser from East to West. Near la Tour-sur-Orb area, they display a fan conglomerates assemblage (St-Xist facies), revealing the tectonic activity of the Bousquet d'Orb / la Tour-sur-Orb border fault, and the uplift of the hercynian domain that provides a persistent supply of coarse debris spreading out to the east.

The Rabejac Fm consists of coarse alluvial fan deposits in the western border, passing toward the basin to red sandstones and mudstones with abundant sedimentary structures (ripple marks, desiccation cracks, footprints and invertebrates tracks), indicating long subaerial exposure. These alluvial fan deposits may be connected with the Saalian volcano-tectonic events.

In this Formation, little Branchiosauridae / Temnospondyls have been mentionned by Heyler (1969). Footprints are numerous with *Batrachichnus salamandroides* (undertracks = *Salichnium decessus* or *S. pectinatus, Limnopus zeilleri*, *Amphisauropus latus,* frequent *Hyloïdichnus major*, *Varanopus curvidactylus* / *Microsauripus acutipes, Dimetropus leisnerianus* and *Dromopus didactylus. Isopodichnus furcatus* Gand, 1994, is very abundant. It is an invertebrate resting trace (cf. *infra.* Gand *et al*., 2008).

Macroflora is often well kept. It is described by Galtier and Broutin (2008).

4. 2. The Salagou Formation: permanent floodplain and playa-lake system

4. 2. 1. The physical environment in the Mérifons area

The hills of Mérifons expose the Salagou Fm that characterizes the most important syn-rift infill. In this area, the fine green carbonate-rich layers hardened regularly the surface, causing beautifull arabesques with high contrats of colors (Fig. 8).

Stratigraphical and sedimentological organisation

The Salagou Fm (F5) corresponds to a 2000 m-thick vertical accretion on the hanging wall of the Aires-Mas Blanc fault (Fig. 3). It consists of dominant pelites in submersive floodplain to playa-lake environment. During this period, the activity of the "les Aires-Mas Blanc" fault controlled the incremental infilling of the basin, and led to an overall divergent (fan-shape) geometry of the deposits (Fig. 2).

The following facies *sensu* Kruseman (1962) have been distinguished:

The "Octon facies" is made of fined grained deposits outcropping widely in the western part of the basin ("Ruffes" landscape). It corresponds to a vertical cyclic alternation of meter- to decameter-thick red massive pelites with cm-thick, yellowish-gray carbonaceous siltstone horizons with desiccation cracks, ripples marks, invertebrate tracks, and rarely, arthropod remains. Some of these latters horizons were mapped, and numbered as R 100 to 1000 reper-marks in figure 4 by Henriot (Cogema, 1988; unpublished document).

Desiccation cracks indicate period of intense evaporation causing water level fall, shrinkage and finely exposure (Fig. 9). During this time, ponds are isolated from terrigenous input, and the carbonates precipitated from the standing water by the related increase of salinity. The gray to green dolomitic intervals are thinly laminated and generally topped by oscillation ripples (wind effect) (Pochat *et al*., 2005), polygonal cracks and footprints. Pelites correspond to extensive sheet floods mobilizing large amount of fine detritus from the source area, and spreading it throughout the basin. On more proximal of zones debris-flow deposits, isolated channel fills develop at the

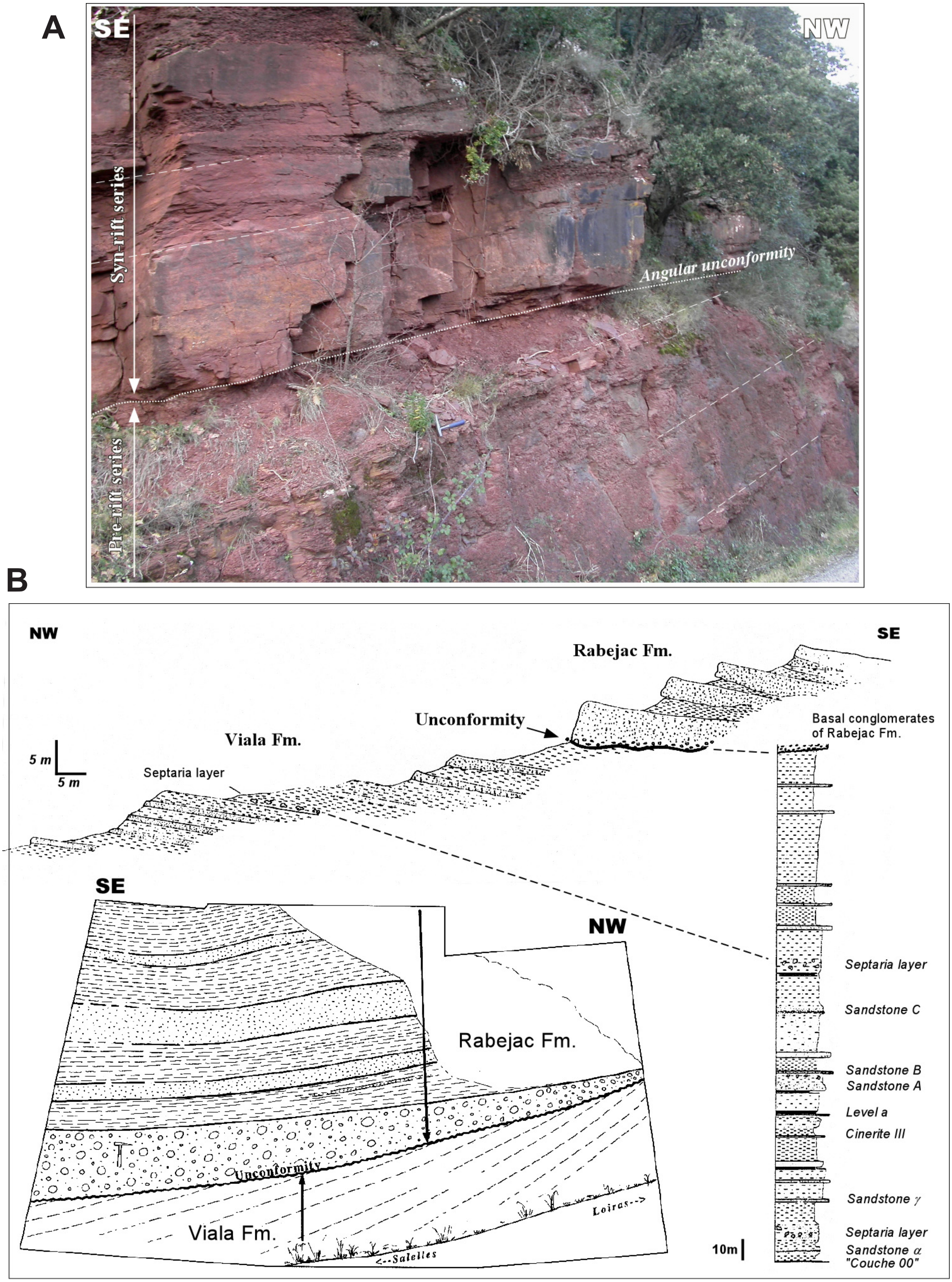


Fig. 7.- A: General view (7A), and detailed log (7B) of the angular unconformity between the Viala Fm (top of the Autunain Group) and the Rabejac Fm (base of the Saxonian Group), along the road from Salelles to Loiras village.

Fig. 7.- A: Vista general (7A), y columna detallada (7B) de la discordancia angular entre la Formación Viala (techo del Grupo Autuniense) y la Formación Rabejac (base del Grupo Saxoniense), por la carretera que une Salelles y Loiras.

base of the flooding event (Fig. 10). In such environment, regular cyclicity could indicate monsoon-like regimes.

Westward to the Octon village, the transition of the Octon facies to the "Merifons facies" is observed. The frequence of the cycles increases drastically. The red mudstones/siltstones part decreased to decimetres, and the carbonaceous desiccation crack-horizons are, apparently, more frequent. The colour of the latter one changes to pale green; often they form large surfaces with beautiful desiccation cracks. The base of the "la Lieude facies", in the top of the "Merifons facies", is marked by the sudden shedding of debris flow conglomerates after hundreds of meters of nearly exclusive pelitic sediments. At this level, Therapsid footprints occur (Gand *et al.,* 2000). Higher, in the profile, the pelitic intercalations disappear between stacked conglomerates and sandstone horizons. The very coarse "la Tour-sur-Orb facies", in the south-west corner of the basin, represents the proximal fan deposits of the "la Lieude facies". The drastical change from the Merifons to the La Lieude facies is still under discussion now: climatic change and/or tectonic activation (Körner *et al.,* 2003; Legler *et al*., 2004).

La Lieude facies: typology of sandstone sequences

Origin of red pelites

Red pelites are mainly composed of clay minerals (in particular kaolinite), fine silt, Fe^{+++} oxides and additional dolomite coming from the erosion of a thick lateritic crust developed on the emerged hercynian belt, and under tropical dry climatic conditions (ferallitisation, Fig. 10). In this sense, the red colour already existed in the transported sediment. It differs from the green colour that indicates syn- to post-depositional diagenetic processes.

Three main types of green horizons are visible:

- Mottled green/red pelites: mark the imprint of fluctuating paleo-watertables;

- Coarse to very fine sandstone beds forming extensive laterally-migrating fluvial channels. The flux of water in these channels is supposed more continuous, with a permanent low-oxygenated water body, allowing early reduction of iron oxides;

-Thin and continuous carbonate-rich layers. This particular facies indicates the development of isolated ponds, were low-oxygenated standing waters evaporate, resulting in carbonate precipitation. Locally, some joints and fractures in red pelites show a centimetre-thick green fringe related to present day drainage by meteoric waters.

Channel sequences

Two main types are sandwiched in the red pelites of la Lieude:

1) The type I visible in front of la Lieude farm, corresponds to isolated decametre-wide and metre-thick red sandstone lenses (Fig. 11A). The base of the channel is entrenched on a dolocrete paleosoil (with numerous rootlet prints and nodules = a). It displays discontinuous pelite- and yellow carbonate-supported (= paleosoil reworking) conglomerates (b) passing to ungraded pelite-rich coarse sandstone (c). The upper part of the channel infill is more organized with trough cross-bedding or plane-parallel bedding (e), indicating sheet-flood processes after the channel abandonment and plugging (d).

This type of isolated channel is supposed to form on the alluvial fan fringe by the development of an ephemeral channel network that deeply incises the emerged and highly weathered red pelites above the regional base level.

2) The type II outcrops north-eastward the footprint surface of la Lieude farm. It corresponds to a meter-thick green-coloured sand layers. From the base to the top, it is composed of medium to coarse, poorly graded clayed sandstones, and locally lag conglomerates that fill desiccation cracks (Fig. 11B), passing to massive or planar-laminated, medium to fine grained sandstone beds (Fig. 12), with possible lateral accretion.

This type of sequence indicates the periodic development of wide shallow channels and sand sheets on the central part of the playa during flooding periods. In this zone, the fluvial network does not entrench, because the base level is at (or just above) the topographic surface. The continuous existence of a shallow to sub-emerging watertable is indicated by the dominance of the green iron-reduced facies.

Ponded fine to very fine green sandstones are associated with the last channel sequence and correspond to cm- to dm-thick non-erosive massive to graded beds, with a lenticular shape. The lateral pinch-out of the sandstone layer displays often desiccation cracks on carbonate-rich silts, indicating the rapid exposure of the margins. Such ponded beds are possibly topped by symmetrical ripples, formed by wind-driven oscillatory processes on very shallow standing waters.

The fossiliferous rills: nature and origin

These sandy bodies were discovered by Jean Lapeyrie who found inside numerous and new well preserved fossils, mainly crustaceans and insects (Gand *et al*., 1997; Garric, 2001). In the Mérifons area, these bodies called "rills / drains" display a typical network organization.

The typical rill vertical section shows three parts (Fig. 13).

- The upper part is widened, U- or V-shaped, and corresponds to the rill *sensu stricto*. The U-shaped rill, more resistant, is generally found intact, while the V-shaped

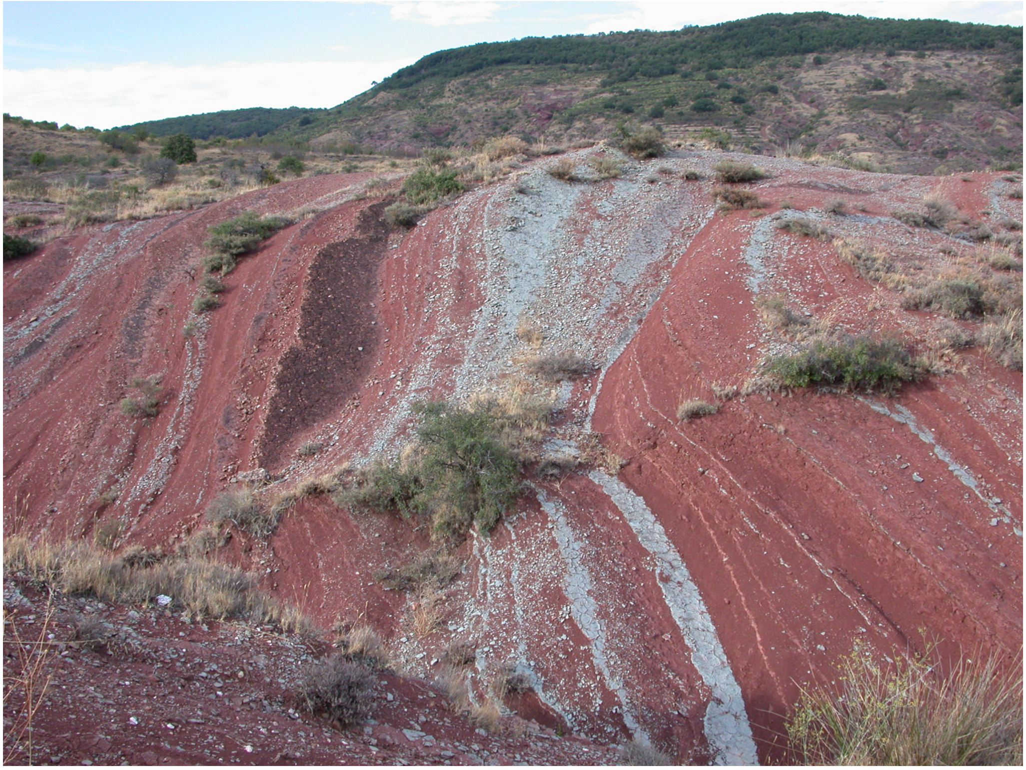


Fig. 8.- Typical landscape of the Salagou Fm. showing thick red pelite packets alternating with thin and regular grey to green carbonate layers with mud-cracks; thickness of these latters = 5 cm..

Fig. 8.- Típico paisaje de la Formación Salagou mostrando un potente paquete de pelitas rojas alternando con delgados y regulares niveles de carbonatos grises y verdes con grietas de desecación. El espesor de los últimos es de 5 cm.

Fig. 9.- Desiccation cracks developed on an exposed dolomite-rich thin layer of the Salagou Fm.

Fig. 9.- Grietas de desecación desarrolladas en un nivel con alto contenido dolomítico en la Formación Salagou.

ones are dislocated into thin slabs.

- The lower part is narrower and sub-rectilinear. In some cases, it resembles a plant root or a vein. The intermediate zone is well marked by a collar and is of a clear green-grey colour and contrasts on the red brown pelite background.

In transverse section, rills appear as sedimentary bodies of small dimensions. Most of the U-shaped rills are isodiametrical (10 cm or a little more), while the V-shaped rills are larger than high. Sometimes, a rill can exceed one meter in overall directions. On the other hand, the lower part or "root" is disproportionate, reaching 2 to 4 m in height for a width not exceeding 10 cm.

In its horizontal plane, the rill is longer than broader; the visible length may reach 10 meters. Exceptionally, the main rill of "les Vignasses" site extends up to 86 m. The U- and the V-shaped rills correspond to well distinct deposits. The U-shaped ones are constituted of poorly graded siltites. They contain green, clayey chloritic pellets and various intraclasts representing a poorly cross-bedded microbreccia facies. They are often very resistant and do not show stratification. They are rich in recrystallized carbonates. The V-shaped rill is formed by finely graded siltites. When the sediment is grey-green, a clear stratification with alternating light and dark laminae (representing periodic kerabitume deposition) is visible. When the sediment is reddish, bedding is less visible but millimetric laminations are obvious in thin section. The fine alternation results in a fragmentation into slabs rec-

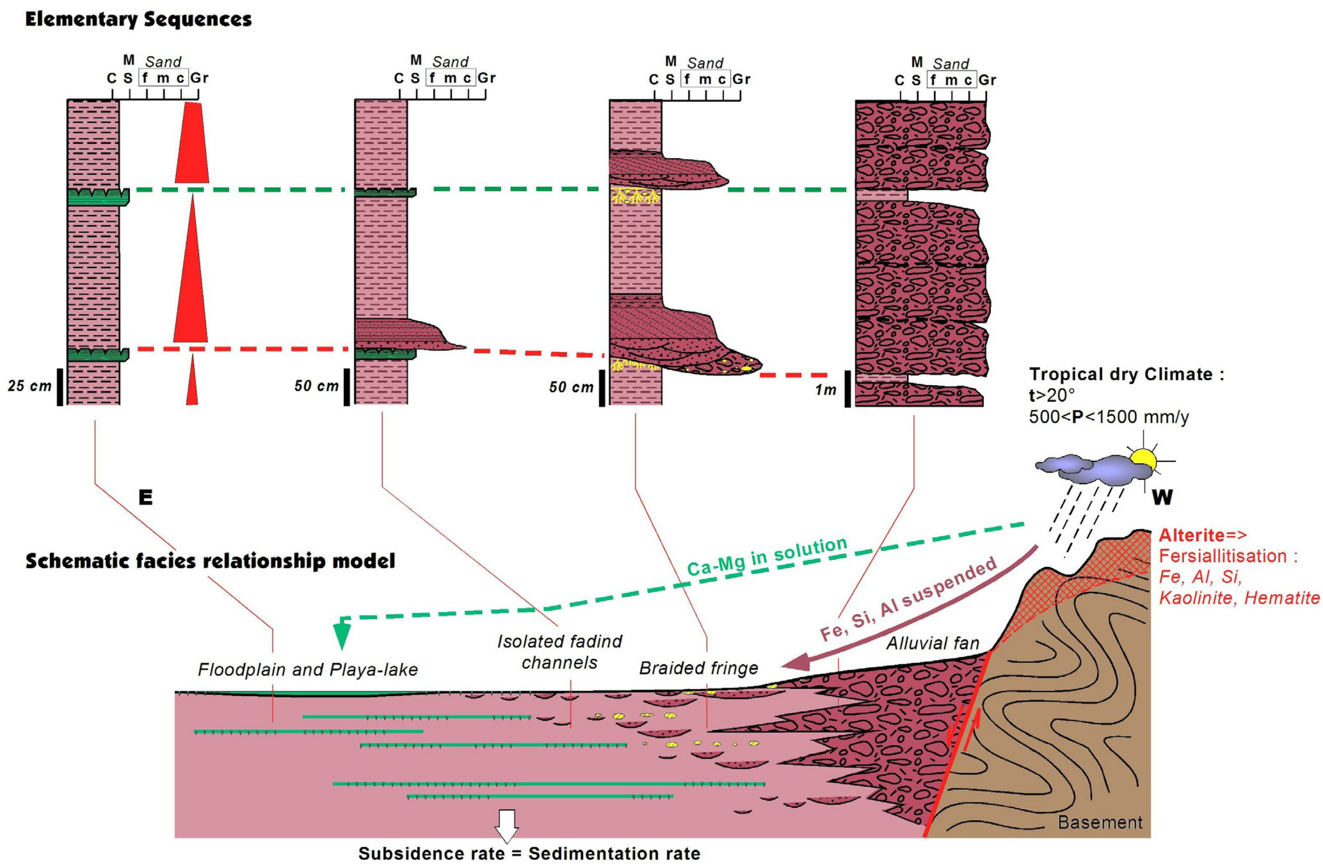


Fig. 10.- Elementary sequences and facies relationship model for the Salagou Fm. (from Lopez and Petit, 2003); Fot the lithology, see fig. 3 (C = carbonates).

Fig. 10.- Secuencias elementales y modelo de relación de facies en la Formación Salagou (modificado de Lopez y Petit, 2003). Para la litología ver la figura 3, C = carbonatos.

ding is clearly concave and connected to the enclosing sediment. By intervals, there are joints corresponding to a deposition of whitish, phyllitic (clays) or reddish (ferric oxides) minerals. Those rill structure and infill are interpreted to be made by rainwater entrenchment on desiccation cracks and/or open fractures. They are scattered in claystones, representing former sediments which were formed in a playa environment under semi-arid tropical conditions.

The abundance of fossils in the rills is supposed to be due to washing/streaming power of rainwater on desiccated surfaces, and to the action of the wind which could concentrate their body fragments, scattered on the surface of the playa. It is probably the case for the insect wings. The presence of Triopsids and Conchostracans may be explained by the deposit of their remains after their death.

Evidences for volcanic activity during the deposition of the playa sediments

In the Salagou Fm, some playa sequences contain pyroclastic material, indicating the permanence of a volcanic activity in the Lodève basin as precised by Nmila *et al.* (1992) and Nmila (1995). The tuffaceous material mixed with detrital sediments, was observed in marker beds R 100 to R 1000 (cf supra). After Nmila *et al*. (1992): "In thin section, these levels display the following main characteristics: quartz typically of volcanic origin (isomorphous faces, volcanic glass inclusions), numerous stretched crystals of feldspar showing more or less advanced degrees of alteration, volcanic glass shards and pumice fragments with I, T, Y, X, etc… type perlite, and oval glass stones formed at the same time showing a degree of alteration. Analcime developed from fragments of acidic volcanic glass during diagenesis. These characteristics are typical of ash falls and provide evidence for the volcanic origin of these marker horizons". The trace elements and the zircon typology demonstrate also an alkaline volcanisme typical of the second French Permian sedimentary cycle (= " Saxonian").

Cyclicity and geochemistry: the climate during the Salagou formation deposition

Sedimentological, geochemical, mineralogical, palaeoecological investigations were carried out in the Lodève basin in order to reconstruct the climatic processes which

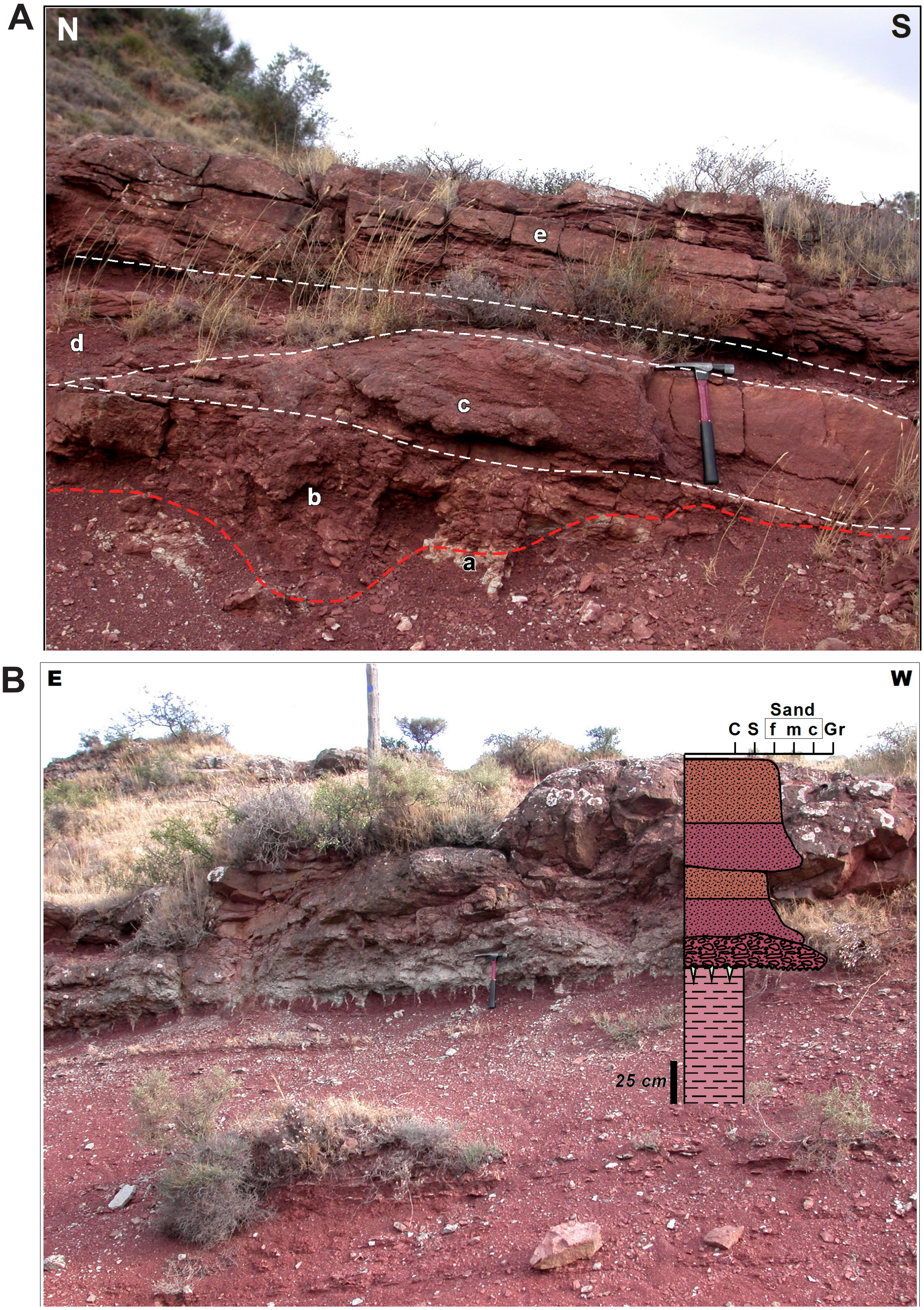


Fig. 11.- Exemples of the two major channel fill sequence types. A: Proximal channel fill sequence entrenched on a paleosoil interval (a = root prints and dolomitic concretions). It is composed of a basal debris-flow deposit (b), passing to muddy coarse sandstone (c) and floodplain pelites (d). A new sequence develops above with a slight lateral migration of the channel axis (e); 11B: Detailed view of the base of a flooding sequence composed of multi-storey channel fills sealing a partly preserved desiccation surface.

B: Ejemplos de las dos principales secuencias de relleno de canales fluviales. A: Secuencia de relleno de canal proximal intercalada con un nivel de desarrollo de paleosuelo (a = impresión de raíces y concreciones dolomíticas). Está compuesto de depósitos debris-flow en la base (b), evolucionando hacia una arenisca de tamaño de grano grueso y con lodos (c) y pelitas de llanura de inundación (d). Una nueva secuencia se desarrolla arriba mostrando una ligera tendencia de migración lateral del eje del canal (e); B: Vista en detalle de la base de una secuencia de inundación compuesta de canales de tipo multi-storey mostrando una superficie parcialmente desecada.

Fig. 12.- General view of superposed distal wide-channel flooding sequences (Type II channel sequence); with local conglomerate and debris-flow deposits; cliff height about 10 m.

Fig. 12.- Vista general de secuencias que representan relleno de inundación de canales amplios y distales (tipo II de secuencia de canal), con conglomerados locales y depósitos de tipo debris-flow. Altura del acantilado = 10m.

control the litho- and biofacies patterns during an Icehouse/Greenhouse transition, as well as the correlation of marine and continental climatic signals. Based on Odin (1986), Henriot (1988), and Nmila (1995), 250 m of the Usclas-St-Privat, Tuilières-Loiras and Viala Fm, as well as 1600 m red beds of Rabejac, and Salagou Fm have been documented. In this last one, about 5.000 cycles have been measured for the cyclostratigraphy (Körner 1999a, b; Körner *et al*., 2003).

The climatic signal could be characterized as follows (Figs. 6, 15, 16). From the Upper Tuilières-Loiras Fm to the Lower Viala Fm., a transition from warm-humid to semi-arid conditions occured. Gypsum-pseudomorphs, desiccation cracks, xeromorphic calcisols and vertisols as well as mesophile fauna and flora were characteristic of the red, brown flood plain deposits of the Viala and the Rabejac Fm. For the Salagou Fm, during the Octon Member deposit, the aridity increased then decreased while the Upperlaying Mérifons Member. At this period, palaeoenvironment and climate of the Lodève basin were probably the following: periodic or episodic strong rain falls, temporary water filled channels contain mass occurences of xerophile organisms (Conchostracans, Triopsids, In-

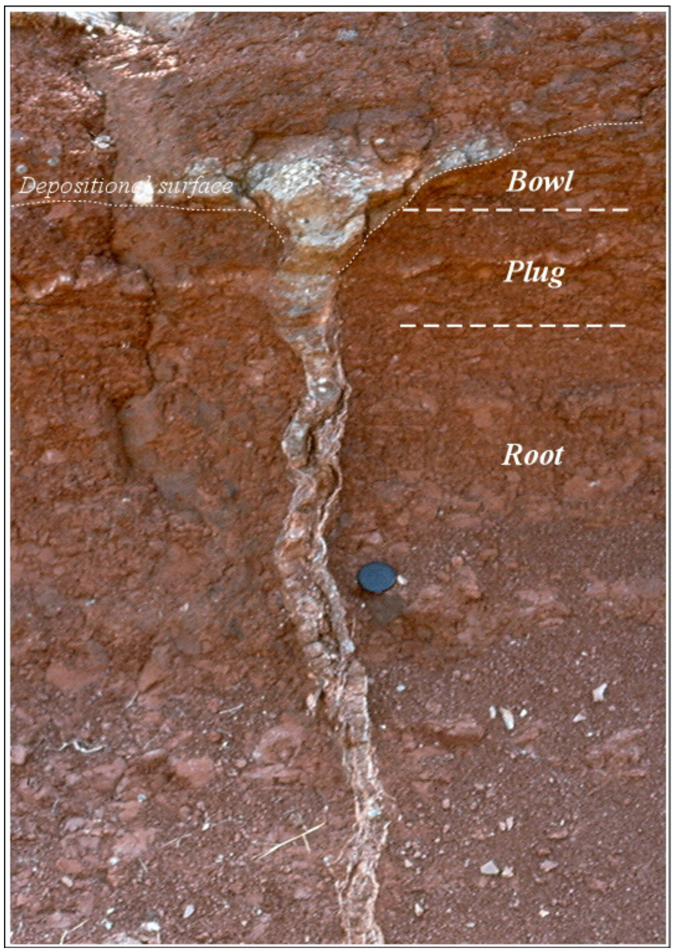


Fig. 13.- Typical rill with a more than one meter root.

Fig. 13.- Sección de un arroyo con niveles de raíces de más de un metro.

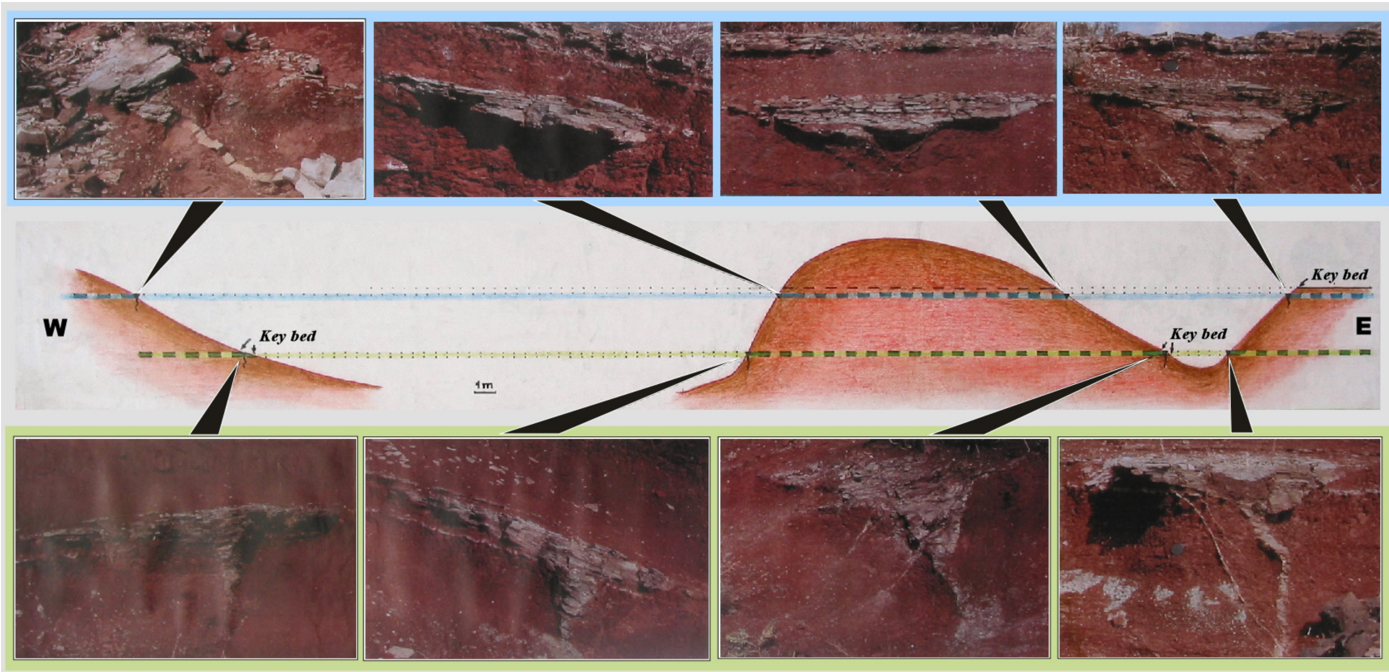


Fig. 14.- General cross-section of two superposed rill levels in the Mérifons area; rill section lengths between 0. 5 – 2 meters.
Fig. 14.- Corte a través de dos niveles superpuestos a lo largo de arroyos en el átrea de Mérifons. La longitud de cada sección oscila entre 0.5 – 2 m.

sects). The same results are known from observations in modern playa and sabkha environments, e.g. in Jordan and Tunisia.

The sedimentary architecture of the la Lieude facies/Member indicates a fast change of sediment supply. These coarse clastics appear suddenly above 2000 m of nearly exclusive fine grained sediments! They result from rapid increasing precipitations and consequently from prograding alluvial fans. Linked to that is the appearance of very diverse tetrapod tracks and the re-occurrence of mesophile flora and invertebrate burrows (*Scoyenia*). This climate change could be possibly the effect of Upper Permian transgressions (Bellerophon Fm, Zechstein-transgression).

4. 2. 2. The life in the playa.

Palaeontological content

In the Lodève Basin, flora, invertebrate and vertebrate remains (fishes, amphibians, reptiles) have been principally collected in the Lower part of the Permian series: grey Formations F1-F2, L1, L2 Members. Higher, various traces of biological origin have been found in the red facies which began at F2-L3 Fm (Fig. 4).

Invertebrate, and vertebrate tracks, burrows, common in the Autunian Group, were a long time only mentionned at the base of the Rabejac Fm. and at the top of the Salagou Fm. (Saxonian Group) (Fig. 4). As the deposits between the two Fm. lacked of fossils, it was generally accepted that the "Saxonian" was azoic, probably because of arid conditions. In fact, it was not the case like shown by the important discoveries of Dr Jean Lapeyrie happened in small silstone rill lenses of the Salagou Fm (Gand *et al.,* 1997).

Invertebrates (Fig. 17)

Conchostracans

They have been found in many levels from the base of the Usclas and St-Privat Fm up to the lower part of the la Lieude Fm. (Fig. 4, 17. 13-14). Species from Salelles and Arieges seem to be somewhat more developed than the Conchostracans of the Upper Rotliegend I, Tambach Fm (Martens, 1983) and Müritz Fm (Germany) dated of Sakmarian/Artinskian (Schneider *in* Hoffmann *et al.,* 1989; Schneider *et al.,* 1995). One form from Arieges is possibly derived from *Lioestheria andreevi* of the Tambach Fm, dated of Wolfcampian from vertebrates (Sumida *et al.,* 1996). Specimens from Sallèles area could be compared with *Isaura harveyi* and *Palaeolimnadiopsis brevis* of the Wellington Fm, (Leonardian of Kansas). Most interesting Conchostracans are found, short below and above the basal fanglomerates of the La Lieude Fm. The 3 mm to 5, 5 mm large forms show a delicate meshwork between the growing lines, a feature also seen in Mesozoic species. This suggests, eventually, a latest Permian age for these beds.

Fig. 15.- Lithological and clay mineral comparison of two typical sequences. Fig. 15. 1 = Octon Facies, Carols area, Fig. 15. 2: Mérifons Facies, Montagne de la Boutine area; Schneider *et al.,* 1999, Schneider and Körner *in* Gand (2004b); lithology: FS, MS, CS = fine, middle, coarse sand, FK, MK, CK = idem for conglomerates .

Fig. 15.- Comparación litológica y e los minerales de arcilla de dos secuencias típicas. 1: Facies de Octon, área de Carols. 2: Facies de Mérifons, área de la Montaña de la Boutine; Schneider *et al.* (1999); Schneider y Corner e*n* Gand (2004b); litología: FS, MS, CS = arena fina, media y gruesa, FK, MK, CK = idem para los conglomerados.

Triopsids and their tracks

Body-fossils: *Triops cancriformis permiensis* and *Lepidurus occitaniacus* have been described, from a large sample composed of thousands of carapaces, thoraco-abdominal fragments and more rarely from intact specimens. They are similar to modern species (Gand *et al.*, 1997) (Fig. 17).

On the basis of the ecological preferences of modern Triopsids and of the sedimentological characteristics of their environment during the Permian, occurrence of shallow, temporary lakes during the deposition of the Salagou Formation was confirmed. These pools, either neutral or slightly alkaline, were scattered across a playa type environment and lasted with the same characteristics during the deposition of the formation which is 2000m thick in the southern part of the basin. Aridity during this long period of sedimentation had been suggested also from sedimentological data (dessication cracks, rubefaction).

Trails

Numerous invertebrate traces (Gand *et al.,* 2004; 2008) have been found (Fig. 17). Some of them are Endichnia: endogenic traces (tubes and burrows) among them delicat *Scoyenia gracilis* common and beautifull in Rabejac Formation. They are probably due to burrowing Insects.

Others are Epichnia: exogene ichnites:

- Furrowing bilobate fine striked tracks *Isopodichnus eutendorfensis* Linck, 1942 from the Mas d'Alary Member levels in Fialhomme wood (Debriette and Gand,

1990) and the Salagou Fm. (near Octon).

- Resting coffee bean-shaped traces *Isopodichnus minutus* Debriette and Gand, 1990, and *Isopodichnus furcosus* Gand, 1994 from the Rabejac and Salagou Fm.

- Walking/nating tracks: *Acripes* (Matthew, 1910) Walter 1983 also found in the whole Permian series are particularly common in the Salagou Formation. Triopsids are the trackmakers; (See Gand *et al.*, 2008).

Insects

Blattodea

Five species of *Phyloblatta* and one of *Opsimylacris* species are recognized (Fig. 17), similar to those observed at the Obora locality of the Boskovice Furrow (Czech) and in the Wellington Fm of the Kansas (Schneider, 1980, 1984a, b). Fragments of about 2 cm long fore wings from Arieges show first indications of a V-shaped cross-veneation pattern, which is typical of the genus *Aisoblatta*. This latter appears, possibly, first in the Uppermost Kungurian and is typical of the German Zechstein and the Upper Permian of China (Schneider, 1983, 1996). Blattoid insects of the Salagou Fm suggest a Kungurian to lower Lopingian age.

Others taxa

The fossil-bearing strata are distributed between the R 300-R 800 reper levels (Fig. 4). The palaeoentomofauna is known from more than 700 specimens, and appears very diverse. Around 12 orders are represented, 3 Palaeoptera (Palaeodictyoptera, Odonatoptera, Diaphanopterodea), 9 Neoptera (Blattaria, Orthoptera, Glosselytrodea, Neuroptera, "Protorthoptera", Caloneurodea, Miomoptera, Protelytroptera, Hemiptera). Four others are of uncertain affinities.

The following insects were described from the Salagou Fm; *Lapeyria magnifica* Nel *et al.*, 1999a (Odonatoptera: Panodialata: Lapeyriidae); *Epilestes gallica* Nel *et al.,* 1999c (Protozygoptera: Permolestidae); *Lodevia longialata* Nel *et al.,* 1999c (Protozygoptera: Permepallagidae), S*axonagrion minutus* Nel *et al.,* 2000b (Odonatoptera: Panodonata: Zygoptera: Saxonagrionidae); Orthoptera: Tettigoniidea; Glosselytrodea…(Béthoux, 2001-2005).

The Odonatoptera are mainly 'Meganisoptera' with several new species of Meganeuridae: Typinae (See Nel *et al.*, 2008). If Protozygoptera are represented, although less abundant than the Typinae, the Permian suborder Protanisoptera is still unknown in the outcrops.

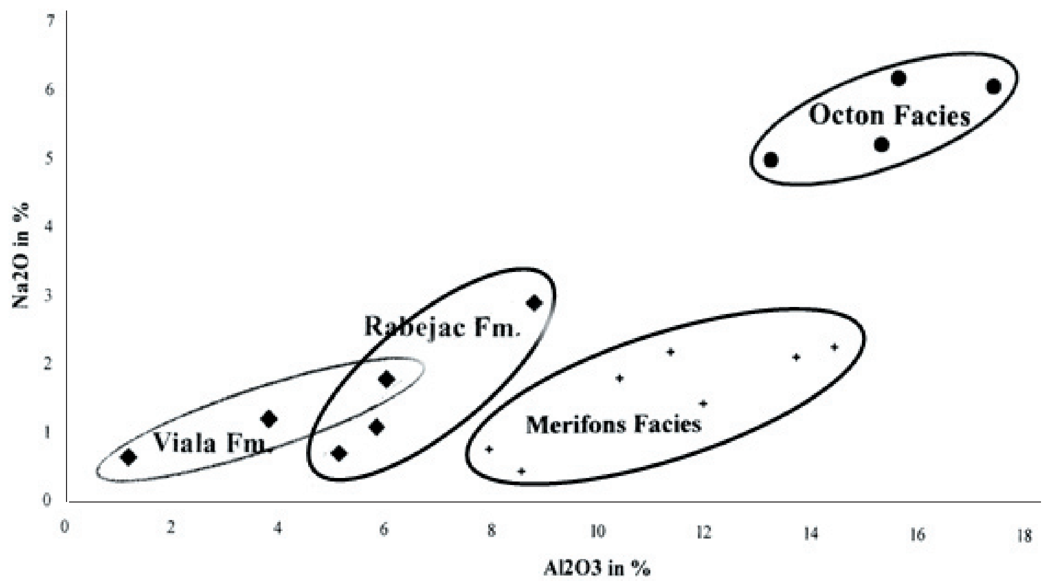


Fig. 16.- Na_20/Al_20_3 ratio for estimation of the Chemical Index of Alteration (CIA), Schneider *et al*. (1999); Schneider and Körner *in* Gand (2004b). High Na_20/Al_20_3 ratios stand for a weak influence of chemical weathering in the source area. Climatic path (respectively with regard to the other Fm): highest precipitation rate in Viala Fm; in Rabejac Fm slightly dryer; maximum of aridity in Octon Facies and in Merifons facies slightly more humid.

Fig. 16.- Relación Na_2O/Al_2O_3 para la estimación de los Índices Químicos de Alteración (CIA), Schneider *et al*., (1999); Schneider y Corner *en* Gand (2004b). La relación alta de Na_2O/Al_2O_3 indicaría una débil influencia de alteración química en el área fuente. Clima (de unas unidades respecto a otras): alta precipitación en la Formación Viala; ligeramente seco para la formación Rabejac; aridez máxima in las facies Octon y ligeramente más húmedo en la facies Merifon.

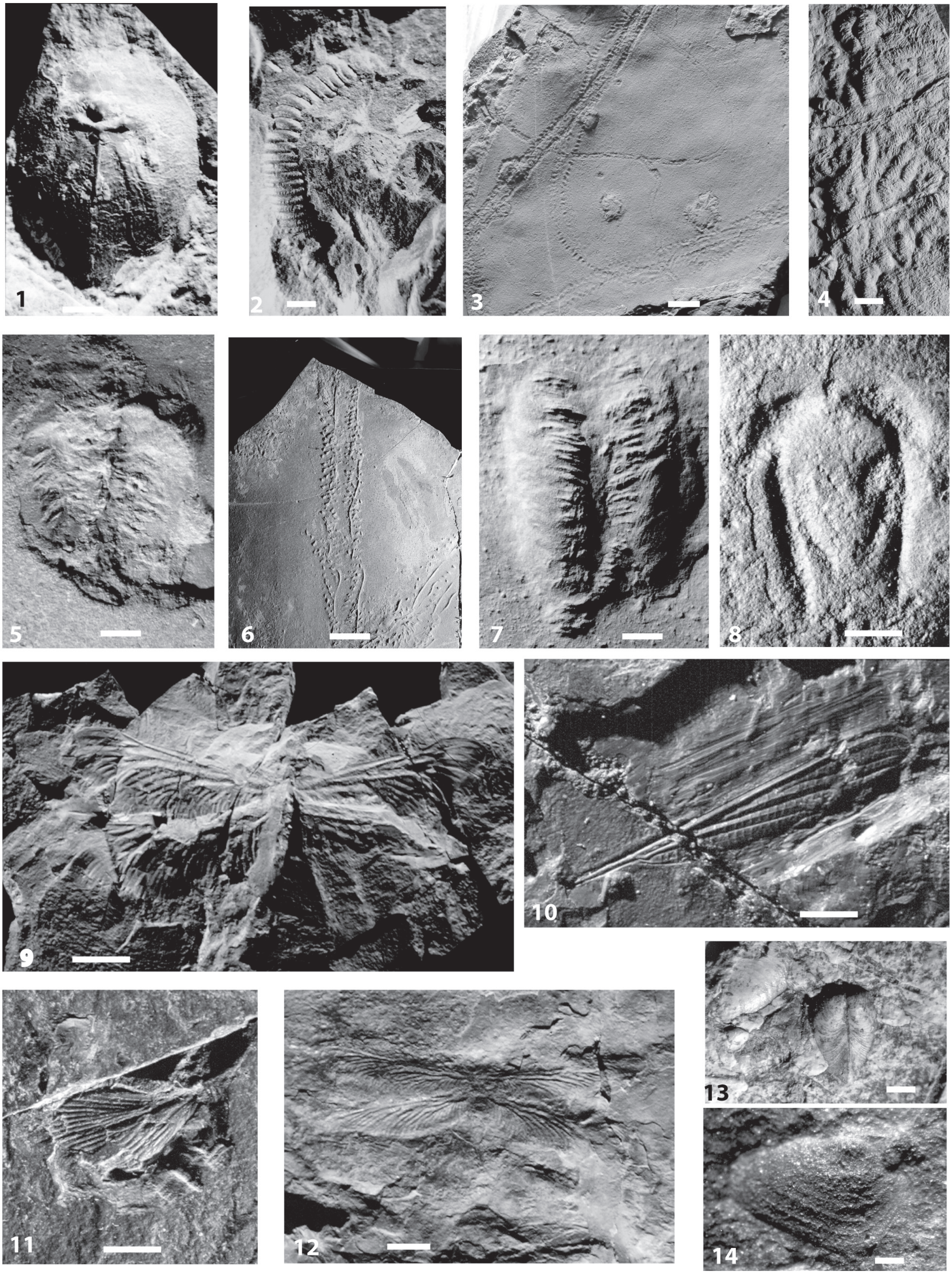


Fig. 17.- Invertebrates of the Salagou Fm. Triopsids: 1 = carapace, 2 = abdomen, 5 = ventral view, 3 and 6 = repichnia, *Acripes*, 4 = *Cruziana problematica* (pascichnia), 7 = *Rusophycus eutendorfensis*, 8: *R. furcosus* both being cubichnia; 9-12: insects, 8: *Lapeyria magnifica* (Panodialata), 10: *Epilestes gallica* (Protozygoptera), 11: Archaeorthoptera, 12: Meganisoptera; 13-14: Chonchostraca; scale = 1 mm for 1, 5, 7, 8, 13, 14; = 5 mm for 2, 4; and = 1 cm for 3, 6, 9-12.

Fig. 17.- Invertebrados de la Formación Salagou: Ver nombres en la versión en inglés.

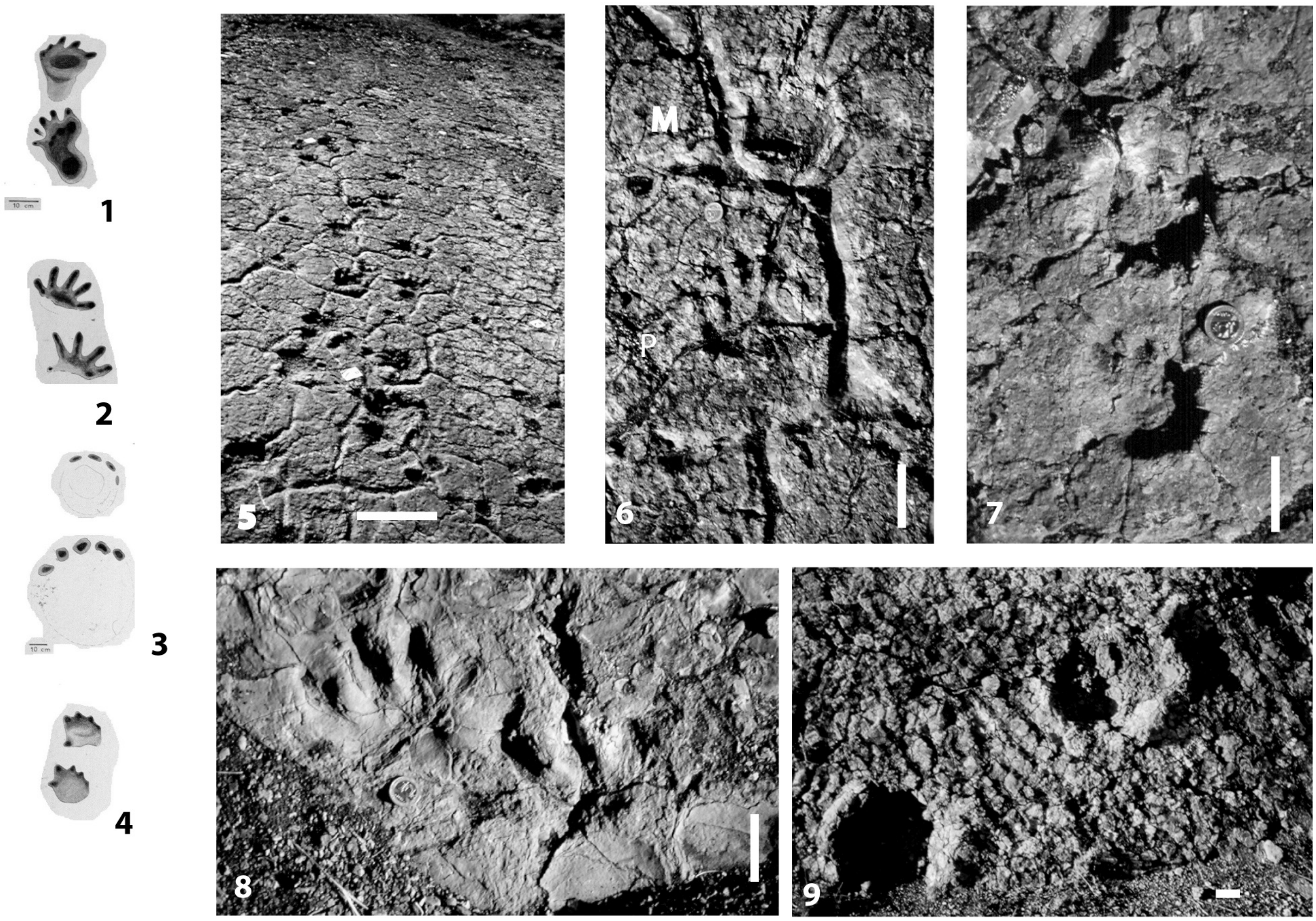


Fig. 18.- Permian footprints of la Lieude Member. 1, 5, 6: Planipes brachydactylus, 1, 6: manus (M) and pes (P); 2, 8: Merifontichnus thalerius manus-pes couple; 3, 9: Brontopus giganteus manus-pes couple for 3, probably only 2 pes traces for 9; 4, 7: Lunaepes ollierorum manus-pes; 5-8: traces probably due to Therapsida; 9 being ascribed to Therapsida or Pareiasauria; scale = 30 cm for 7 and 5 cm for 6-9.

Fig. 18.- Impresiones de pisadas pérmicas del Miembro Lieude: Ver nombres en la versión en inglés.

Archaeorthoptera are represented by several families and species, described in numerous papers by Béthoux *et al*. (2001-2004).

Hemiptera occur in the shape of a 'cercopoid-like' wing and a Cicadomorpha: Prosbolidae, the latter being already known from the Late Permian of Russia and Siberia. The same is true for Protelytroptera which are reported for the first time in France.

The Endopterygota include several species of Mecopterida and Neuroptera. Coleoptera, Raphidioptera, Megaloptera have still not been found in the Lodève basin sites whereas they exist in the Early and Middle Permian of Siberia and of USA.

Trails

Curiously, for this time, only a few samples of *Lithographus*, a walking insect track, were found, although numerous wings and sometimes body fossils have been gathered in the Saxonian Group (Gand *et al.,* 1987; see Gand *et al*., 2008).

Taphonomy

For this time, the palaeoentomofaunal material is almost limited to wings, broken frequently. The body remains found in rills/channels belong to adults. Current taphonomic hypothesis concerning the Salagou Fm formation suggests that animals were dislocated before fossilisation and exposed for a variable time, on areas, close to the fossiliferous sites. After that, sedimentologic events concentrated insects in rills/channels. Possibly, rain and wind or running waters accumulated organic remains in small depressions, during drying periods.

Absence of larvae, in spite of numerous remains of Odonatoptera, should have several possible origins. They could be developped in different areas or fossiliferous events could have been seasonal, when larvae were absent. But, this seems unlikely because of various different living insect larvae are developing during all the year. May be, also, the delicate larvae bodies were easily destroyed by necrophagous than those of adults.

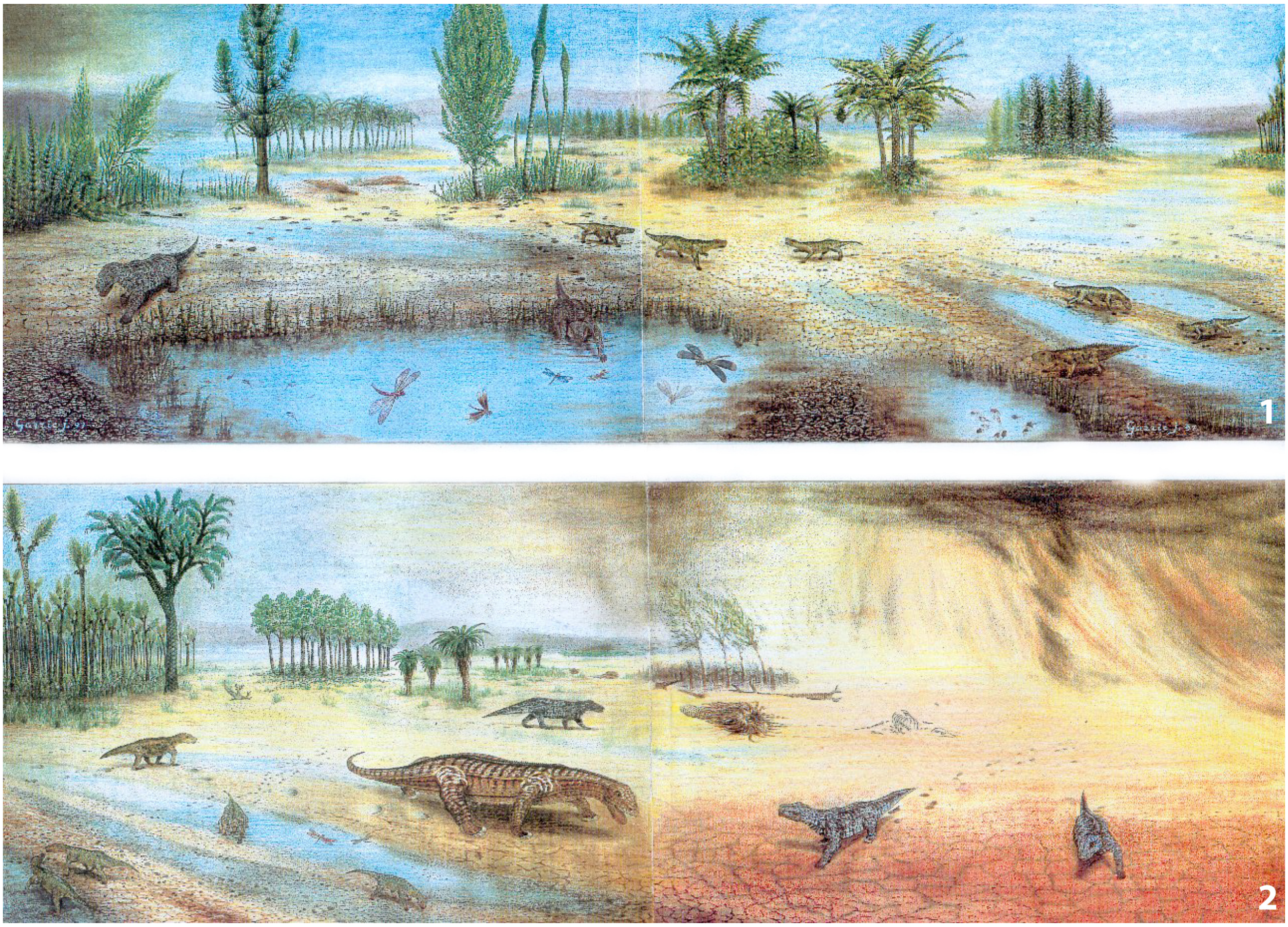


Fig. 19.- Tentative reconstruction of the physical and biological environment by J. Garric when animals made footprints near la Lieude (Gand *et al*., 2000). To obtain the full landscape, put the fig 19. 2 at the rigt of the fig. 19. 1. Fig. 19. 2: the biggest animal, possibly a Dinocephalian, about 5 m long, is walking to the SE. It is the trackmaker of *Brontopus giganteus, B. circagiganteus*. In front, two Titanosuchians, 2 m long, are moving southward, leading *Planipes brachydactylus.* Behind the Dinocephalians are trackmakers of *Lunaepes ollierorum* (Therapsida of 1, 20 m long); Fig. 19. 1: Above the largest pond, three trackmakers of *Merifontichnus thalerius*: Therapsida possibly, Dicynodonts of 1,50 m long. The biggest animals marks *P. brachydactylus*; Note in ponds, Triopsids and plants: Calamariacea and Gymnosperms.

Fig. 19.-Reconstrucción tentativa de del ambiente físico-biológico por J. Garric en el momento en el que los animales producían las pisadas en las proximidades de L Lieude (Gand *et al*., 2000). Para obtener una completa reconstrucción del paisaje, colocar la figura 19.2 a la derecha de la 19.1. La figura 19.2 muestra al animal más grande, posiblemente un Dinocephalian, aproximadamente de 5 m de longitud, que estaba andando hacia el SE. El que realiza la impresión es *Brontopus giganteus*, B. Circagiganteus. En frente, dos Titanosuchidos de unos 2 m de longitud y moviéndose hacia el S, y por delante, *Planipes brachydactylus*. Detrás de Dinocephalian los que imprimen las huellas de *Lunaepes ollierorum* (Therapsida de 1,20 m de longitud); En la figura 19.1: sobre la charca más grande, aparecen tres impresores de pisadas de *Merifontichnus thalerius,* posiblemente Therapsida, Dicynodont de 1,50 m de longitud. La impresiones del animal más grande *P. Brachydactylus;* en las charcas aparecen también Triopsidos y plantas: Calamariacea y Gimnospermas.

Vertebrates

Footprints (Figs. 5, 18, 19).

Near "la Lieude", on a slab surface, more than one thousand of footprints are distributed in twenty trackways which mesures to 220 m in length. They have been found on one calcareous siltstone level in the site. This latter is located in the Saxonian summit of the Salagou Formation, Fig. 4, 5).

Gand *et al.* (2000) have distinguished following ichnotaxa: *Lunaepes ollierorum*, *Merifontichnus thalerius*, *Planipes brachydactylus* and *Brontopus circagiganteus*. All are attributed (with possibility or probability) to Therapsida or to "Therosauria", except *Brontopus circagiganteus* that could be due to Caseids. All these animals of 1 to 5 m long, lived in a playa environment. The biological and sedimentological data infered from "la Lieude" footprint levels compared with those provided by the track orientations, suggest that most of the animals crossed a sandy channel bank with plants and walked toward the South for the majority. They could go to the lake of the playa, close to "la Lieude" footprints area, they have just trampled on.

Body-fossils

In the “la Lieude Member”, Ellenberger (1983a) mentionned some bone beds, but without giving precise locations. In 2001, Frank Körner discovered elements of a probable Pelycosauria in the Salagou river border. Under a working European convention (Gand *et al.*, 2000), since this discovery, excavations are organized by one of us (GG) to extract other skeletal remains. Thus a Tupilakosaurid amphibian have been recently found and described (Werneburg *et al.*, 2007).

5. Conclusions

Large, continuous outcrops and dense borehole network for Uranium exploration, allow to constrain the second sedimentary cycle of the Lodève Permian basin. This latter corresponds to a large playa system bordered to the south by a major synrift normal fault, and onlapping both previous Upper Carboniferous sediments and the Hercynian basement in the Northern and the Eastern part of the basin.

Playa sediments of the central part of the E-W elongated half-graben basin turn westward in stacked, thick debris-flow dominated alluvial fan sequences sealing the hanging-wall of an active normal fault along the Orb valley. Alternating arid and humid cycles, on the thick lateritic profiles developed on the drainage basin of the Montagne Noire Hercynian belt controled the periodic flooding of the playa system. During more humid periods, large amount of debris and red clays are vehicled as high density bedload by an ephemeral stream network, and they are expended as extensive thinning upward sheetflood sequences at the playa base level. This metre to decametre-thick climatic cycles record successive inundation-emersion sequences (moonson-like regime?), with a global increase of aridity during the deposition of the lower part of the Salagou Fm, followed by a reverse tendency on the upper part.

The playa sequences reach about 2000 m of total thickness in the hanging-wall of the southern bordering fault, recording the overall synrift differential subsidence of the basin during about the Upper Cisuralian to Lower Lopingian time.

Traces of life of the Lodève Permian playa were firstly described, in part, as animal tracks and feeding burrows developed on sub-emersive surfaces, and as roots and poorly preserved plant debris at the top of flooding sequences. More recently, a particularly abundant and well preserved invertebrate fauna (thousands of body-fossils, and hundreds of insect wings) were discovered, trapped in silty fossiliferous rills associated to watertable rise and subtile washing and streamean power cleaning of rainwaters on desiccated surfaces. All the insect orders described elsewhere (USA, Russia) are represented here by several families and species. In particular, a 50 cm wingspread Odonata have been discovered in these traps.

This ephemeral ponded micro-environments favoured the seasonal development of small crustaceans like Conchostraca and Notostraca. The latter gives numerous swimming and furrowing traces on subaerial surfaces, delicately fixed by cyanobacterial mats. These short-live blums argue for the aridity of the climate during this period.

Subaerial surfaces expose numerous vertebrate tracks, and more particularly reptilian footprints, with an enigmatic overall increase of their size from the base to the top of the series. At the base, in the Rabejac Fm, both reptilians (Pelycosauria, Parareptilia, Lepidosauria), and amphibians (Temnospondyls) show a moderate size ranging from decimetric to metric; the latters being less abundant and diversified. On the contrary, the upper part of the Salagou Fm is dominated by mammalian reptiles and in particular, pluri-decimetric footprints of large, weighty herbivorous preserved on river bank deposits. Recent European fieldworks, in the vicinity of the outcrops of vertebrate tracks, yielded Pelycosauria bones dispersed into a muddy, debris-flow deposit, arguing for the periodic colonization of vegetaded areas of the playa by herbivorous herds.

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