10

Sedimentary Tectonics and Stratigraphy: The Early Mesozoic Record in Central to Northeastern Mexico

José Rafael Barboza-Gudiño
Universidad Autónoma de San Luis Potosí, México

1. Introduction

The stratigraphy has traditionally been conceived as a geological science based on the description and subdivision of rock successions in some kind of units, following the International Stratigraphic Guide or the North American Stratigraphic Code and accord to lithostratigraphic criteria. Diversification or development of modern analytical techniques and emerged new concepts and models of sedimentary, volcanic, plutonic or metamorphic settings, associated to specific geotectonic regimes, offers new possible approaches for stratigraphic subdivision. Accord to these new criteria, revision of numerous sequences is required in order to establish a direct relationship between subdivision and events or environments in space and time, prevailing genetic or provenance criteria over the simple lithological or chronological criteria. Tectonic events are typically recorded in sediments being deposited at the same time, in such a way; each stratigraphic unit can be related to an specific geologic process or tectonic setting.

The composition of a sedimentary rock provides us information that allows interpreting several kinds of relations, like source land composition or provenance. By siliciclastic rocks, their mineral and clastic components established through petrographic studies, are characteristic of specific tectonic settings, and in this way usefully for stratigraphic subdivision, representing a signature for each unit. The heavy minerals in a siliciclastic rock are also a useful tool for the characterization of a sedimentary rock and their possible sourceland. Geochemical studies are also useful to complement stratigraphic subdivision and classification constraining provenance and a geotectonic regime or stage related to each stratigraphyc unit. Finally geochronology and especially the detrital zircon geochronology of sillisiclastic rocks is today a poderous tool to determine a maximal deposition age of a layer but also a provenance through the several clusters of individual zircon ages established by the U-Pb method. The Goal of this chapter is to present some criteria for the stratigraphic subdivision and establishment of stratigraphic units utilizing the modern, petrographic, geochemical and geochronologic thechnicks through a case study of the Early Mesozoic succession outcropping in central to northeastern Mexico (Figure 1).

After Laurentia-Gondwana collision during Late Paleozoic time, the actual central Mexico was occupied by a remnant basin at the westernmost culmination of the Ouachita-Marathon belt. This basin was bounded by a subduction zone to the east, where their oceanic floor subducted eastward below Pangea and by a transform margin to the north in southern Laurentia. The subduction process caused deformation and metamorphism during the Late Paleozoic, producing the Granjeno schist, exposed in some places in the Sierra Madre Oriental. Towards the latest Permian-Early Triassic, tokes place magmatic activity, related to a low stress stage of the same subduction process, producing the east Mexico Permo-Triassic Magmatic arc. Such ancient active margin, was probably abandoned since the Early Triassic, and a new subduction zone evolved to the west towards the end of the Triassic time,

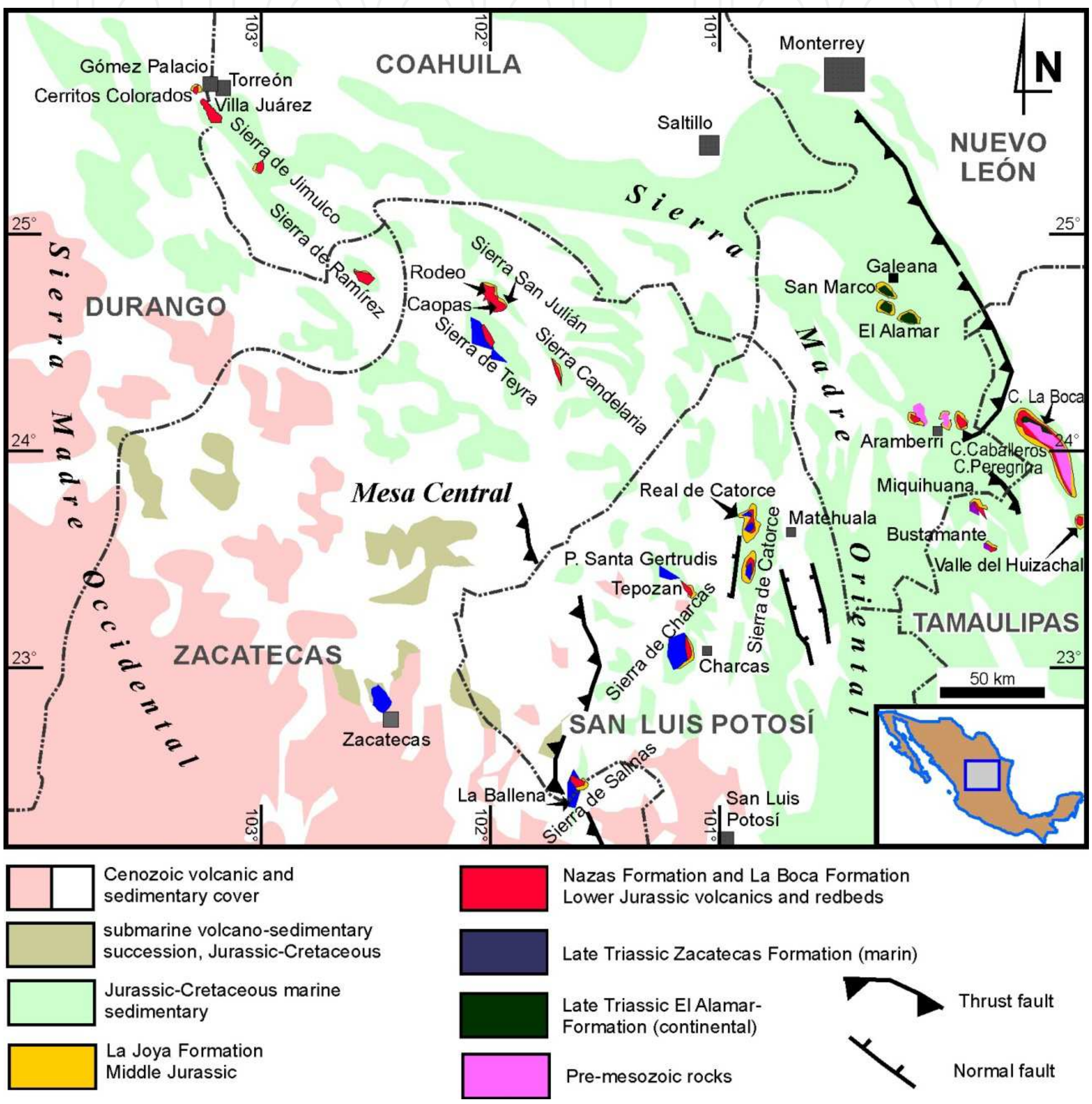


Fig. 1. Pre-Late Jurassic localities in central to northeastern Mexico modified after Barboza-Gudiño et al. (2008). Shown are Late Triassic exposures of the marine and continental post-Triassic units, exposures of pre-Mesozoic crystalline rocks, in some cases interpreted as areas of no deposition during the Triassic, and the main exposed volcanic centers of the Early Jurassic volcanic arc

producing new deformation in the Mesa Central and subsequent a new continental volcanic arc during the Early Jurassic. The earliest deposits in the pacific sub-basin located today in central Mexico, are represented by Triassic and Jurassic successions whose subdivision has been able to establish on the basis of sedimentary tectonics criteria, assigning a specific geotectonic setting or a distinctive provenance to each defined stratigraphic unit.

2. Research methods

The petrography and specially the point counting of mineral and clastic components from a sedimentary rock, is the traditional technique to determine a possible provenance in terms of their typical mineral and clastic components. Each sediment, accord to their mineralogical and clastic content, can be related to a kind of source area, like plutonic or volcanic, felsic or mafic, recycled sedimentary or metamorphic, and also related to an specific tectonic setting or tectonic regime, like stable continental craton, recycled orogen, volcanic arc and block faulted continental basement, including continental rifts. Triangular Quartz-feldspar-lithics (Q-F-L) diagrams after Dickinson (1985) are the most conventional plots to assign in an empirical way a tectonic setting of provenance for each studied rock. Figure 2 shows several triangular diagrams used for different approaches in provenance studies and based on the

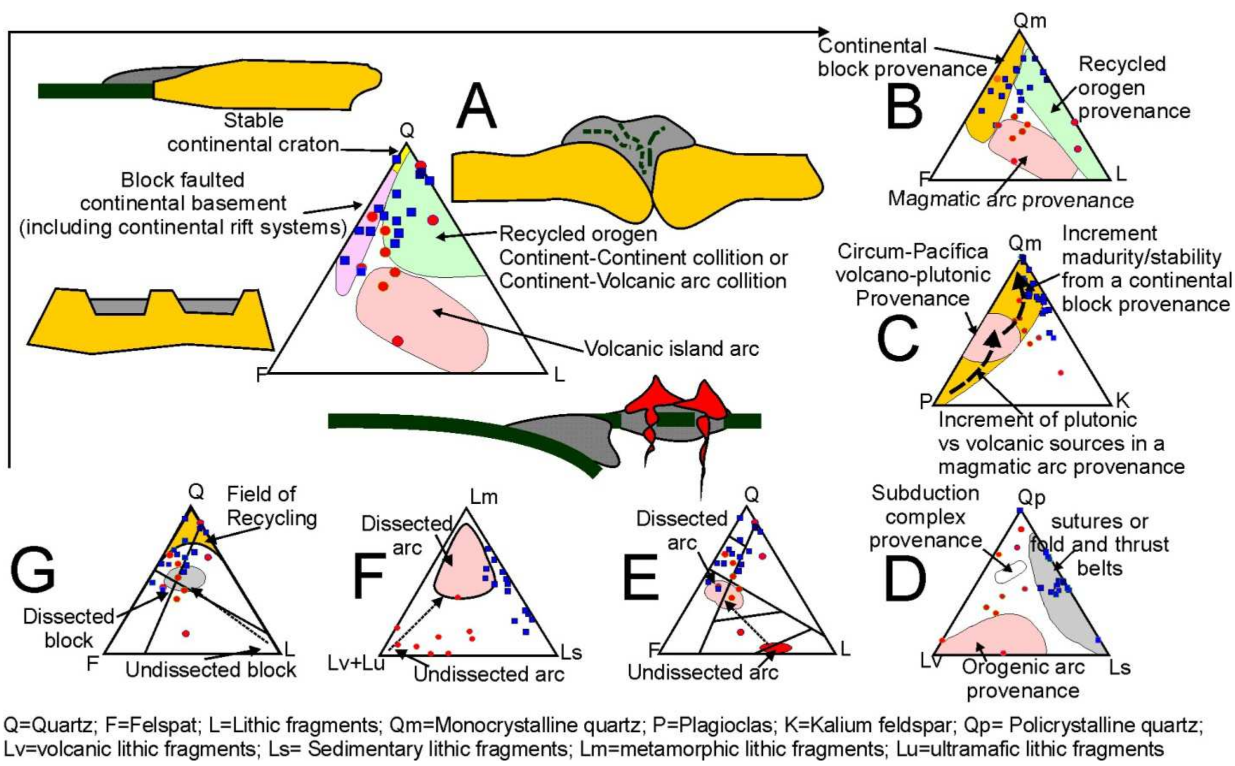


Fig. 2. triangular diagrams for discrimination of the tectonic regimes of provenance: Q-F-L (A), Qm-F-L (B), Qm-P-K (C) and Qp-Lv-Ls-diagrams (D), modified after Dickinson et al. (1983), Dickinson (1985); diagrams Q-F-L and Lm-LV+Lu-Ls after Marsaglia & Ingersoll (1992), modified by Garzanti et al. (2007) for discrimination of dissected/undissected magmatic arc settings (E, F) and diagram Q-F-L after Garzanti et al. (2007) for discrimination of dissected/undissected blocks. Ploted are in all diagrams, results of point counting (after Barboza-Gudiño et al., 2010) in samples from the Triassic El Alamar Formation from northeastern Mexico (quadrangles), as well as samples from the Early Jurassic La Boca Formation (circles). See discussion in text

abundances of distinct clastic components. The heavy minerals content of a siliciclastic sediment or sedimentary rock is also diagnostic for their provenance and in this way also a tool for stratigraphic correlation and subdivision, paleogeographic reconstruction and also to interpret flow patterns for a deposit.

Geochemical approaches complement provenance and stratigraphic studies, supporting interpretation of tectonic regimes related to source areas as well as correlation and subdivision of sedimentary and volcano-sedimentary successions. McLennan et al. (1993) recognized five provenance components or terrane types on the basis of whole-rock chemical and Nd-isotopic composition, incluiding: 1) old upper continental crust, 2) recycled sedimentary rocks, 3) young undifferentiated magmatic arc, 4) young differentiated magmatic arc and 5) other exotic components, like ophiolites. Mayor elements, trace elements, including rare earth elements (REE) as well as several isotopes can be indicative of sedimentary processes and sedimentary-tectonic regimes. For such geochemical studies shale are very appropriate but also fine grained sandstone because their heavy mineral content that reflect several sedimentary processes or information related to the source areas, through their REE and other trace elements or isotopic relations. Nd isotopic composition can be indicative of intracrustal igneous differentiation processes, enrichment on large ion-lithofiles elements is linked to provenance composition, and alkali-alkaline earth depletions is related to weathering and alteration processes. Finally, Zr and Hf enrichments are a direct consequence of heavy mineral enrichment on sediment and high Cr abundances is commonly related to ultramafic sources.

The U-Pb geochronology from detrital zircons has become a fundamental tool in stratigraphic studies. The most exciting results are those of the laser-ablation multicollector inductively coupled plasma mass spectrometry (LAMC-ICPMS). It is a rapid and relative cheap analytical technique that allows in an hour ca 40 age determinations from individual zircons, or from specific zones in a crystal, thanks a micron-scale spatial resolution through beam sizes in the range of 10 to 50 microns. Crystallization ages of igneous rocks, maximal deposition ages of siliciclastic sediments, and provenance analysis are the main kinds of data offered by this technique. U-Pb ages can also be performed in other minerals like sphene, to determine cooling ages in magmatic rocks, or monazite, for metamorphism age determinations. A detrital zircon analysis is based on the age determination from ca. 100 individual zircons by the LAMC-ICPMS technique. The obtained zircon age populations, represent the several blocks or source areas for the clastic components of the rock, and theoretical the youngest zircon or cluster can be considered as the maximal deposition age of the rock or sampled layer from the sequence.

For each analysis, the errors in determining $^{206}Pb/^{238}U$ and $^{206}Pb/^{204}Pb$ result in a measurement error of ~1-2% (at 2-sigma level) in the $^{206}Pb/^{238}U$ age. The errors in measurement of $^{206}Pb/^{207}Pb$ and $^{206}Pb/^{204}Pb$ also result in ~1-2% (at 2-sigma level) uncertainty in age for grains that are >1.0 Ga, but are substantially larger for younger grains due to low intensity of the ^{207}Pb signal. For most analyses, the cross-over in precision of $^{206}Pb/^{238}U$ and $^{206}Pb/^{207}Pb$ ages occurs at 0.8-1.0 Ga. The detrital zircon geochronology allows the comparison of the results from the analyzed samples, in order to compare in addition to their maximal age of deposition, all provenance similarities as a signature that can also be used in some cases as a criterion for stratigraphic subdivision and correlation.

For a detrital zircon analysis, consisting usually of the age determination of 100 individual zircons, a sample of approximately 10-12 kg of fine to middle grained sandstone is prepared. The mineral separation involves crushing of the sample to gravel size on a jaw crusher and posterior pulverizing of this material on a roller mill to reduce it to a fine sand size. The gravity separation consists of a first step on a Wilfley table that separate denser grains from light grains by passing of the sample and water flow over the table that vibrates synchronically. After this first gravity separation, several magnetic minerals and magnetite or iron particles can be removed with a hand magnet, thereafter the next recommended step for separation of the zircons, is by using of methylene iodide (MI), also known as diiodomethane. In all the cases under an operating fume hood at laboratory and with properly protection for eyes and all the skin because it is a potentially hazardous chemical. Finally a Franz magnetic separator allows separation of heavy minerals according to their magnetic susceptibility. Next step before the analysis is the zircon crystals mounting in epoxy, finnaly the mounted crystals are polished to half-thickness.

By the analysis on a LAMC-ICPMS system, material is ablated from a zircon surface, the laser operates at a wavelength of 193 nm with spot sizes between 10 and 75 microns, the ablated particles are carried in helium gas into the multicollector-ICPMS. Sample preparation and analysis techniques are described in detail by Gehrels et al. (2006). Table 1. shows unpublished data of detrital zircons, obtained from a sample collected in the Late Triassic Zacatecas Formation, at La Ballena Zacatecas, south of Salinas, San Luis Potosí. In figure 3, all zircon data are plotted as a Pb/U concordia diagram (Figure 3A) and a relative age probability curve (Figure 3B), following procedure and algorithms of Ludwig (2003). Such plots show each age and its uncertainty (measurement error) as a normal distribution, and add all ages from a sample into a single curve. The analysis was performed in the Arizona LaserChron Center, University of Arizona at Tucson, following the separation and analysis techniques described above, with a New Wave/Lambda Physic DUV193 Excimer laser (operating at a wavelength of 193 nm) using a spot diameter of 15 to 35 microns and a Multicollector ICPMS GVI Isoprobe.

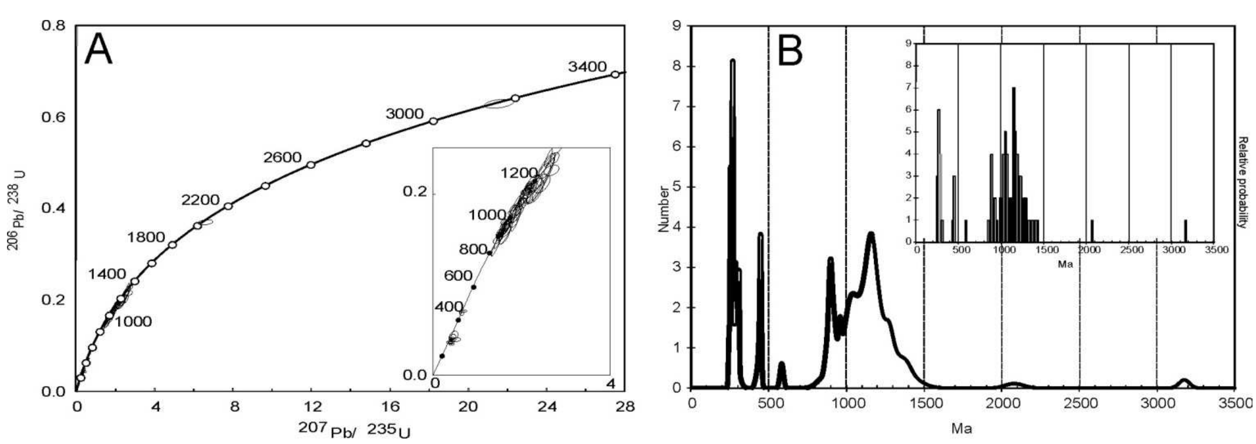


Fig. 3. Plots of zircon ages obtained from sample LB-18: A. Concordia diagram, see detail for the younger zircons, B. Relative Probability curve and histogram, the main populations are Grenvillian (900-1200 Ma), panafrican (500-600 Ma) and Early Paleozoic (400-450 Ma) as characteristic of peri-Gondwanan terranes and finally, a prominent permo-triassic cluster, typical in all samples from north-central and northeastern Mexico, showing a great influence of the East Permo-Triassic Magmatic Arc

U (ppm)	^{206}Pb / ^{204}Pb	U / Th	^{206}Pb* / ^{207}Pb*	± (%)	^{207}Pb* / ^{235}U*	± (%)	^{206}Pb* / ^{238}U	± (%)	error corr.	^{206}Pb* / ^{238}U*	± (Ma)	^{207}Pb* / ^{235}U	± (Ma)	^{206}Pb* / ^{207}Pb*	± (Ma)	Best age (Ma)	± (Ma)
203	9195	1.5	16.9582	10.6	0.3155	10.8	0.0388	2.0	0.19	245.4	4.9	278.4	26.2	565.9	230.8	245.4	4.9
123	7610	1.1	16.5928	21.8	0.3319	21.9	0.0399	1.0	0.05	252.5	2.5	291.0	55.4	613.2	477.1	252.5	2.5
183	13210	1.7	18.9447	12.3	0.2941	12.3	0.0404	1.0	0.08	255.3	2.5	261.8	28.4	319.5	279.6	255.3	2.5
177	21035	2.4	17.5712	5.9	0.3263	6.1	0.0416	1.5	0.24	262.7	3.8	286.8	15.2	488.1	130.7	262.7	3.8
256	22170	1.9	18.9409	6.8	0.3068	7.2	0.0421	2.3	0.32	266.1	5.9	271.7	17.2	320.0	155.7	266.1	5.9
135	13940	1.3	19.7009	8.2	0.2950	8.3	0.0422	1.5	0.17	266.2	3.8	262.5	19.2	229.9	189.5	266.2	3.8
177	11875	1.8	19.4868	5.5	0.2992	5.9	0.0423	2.1	0.36	267.0	5.5	265.8	13.7	255.1	125.9	267.0	5.5
209	25115	2.7	18.2658	7.1	0.3215	7.1	0.0426	1.0	0.14	268.9	2.6	283.0	17.6	401.9	158.3	268.9	2.6
325	5030	2.9	13.6809	13.2	0.4348	13.5	0.0431	3.0	0.22	272.3	7.9	366.6	41.6	1016.6	268.2	272.3	7.9
282	23350	1.6	18.2460	5.3	0.3419	5.4	0.0452	1.2	0.22	285.3	3.3	298.6	14.1	404.3	118.9	285.3	3.3
82	230590	4.6	17.8439	13.5	0.3616	14.0	0.0468	3.6	0.26	294.9	10.4	313.4	37.8	454.0	301.6	294.9	10.4
153	11715	1.3	18.6630	11.0	0.3471	11.1	0.0470	1.5	0.13	295.9	4.3	302.5	29.0	353.5	249.0	295.9	4.3
108	5045	1.3	17.8777	17.7	0.3652	19.2	0.0474	7.6	0.39	298.3	22.0	316.1	52.3	449.8	395.8	298.3	22.0
118	7905	1.5	17.4578	8.0	0.3862	8.1	0.0489	1.0	0.12	307.8	3.0	331.6	22.9	502.3	177.4	307.8	3.0
429	14630	1.6	16.1814	4.9	0.5894	6.1	0.0692	3.7	0.60	431.1	15.4	470.5	23.1	667.1	105.0	431.1	15.4
299	35260	51.2	17.5955	5.1	0.5553	5.4	0.0709	1.8	0.33	441.3	7.6	448.4	19.5	485.0	112.0	441.3	7.6
138	21790	0.9	18.0138	3.8	0.5486	3.9	0.0717	1.0	0.26	446.3	4.3	444.1	14.0	432.9	83.7	446.3	4.3
116	11240	7.5	16.6156	5.5	0.5990	5.6	0.0722	1.1	0.19	449.3	4.7	476.6	21.3	610.2	118.6	449.3	4.7
355	30470	4.0	15.6006	4.0	0.8361	4.5	0.0946	2.0	0.46	582.7	11.4	617.0	20.7	744.9	84.4	582.7	11.4
686	306140	37.7	13.7685	2.1	1.4009	5.8	0.1399	5.4	0.93	844.0	43.0	889.3	34.5	1003.6	42.0	844.0	43.0
204	90590	5.0	14.2983	2.4	1.3954	2.8	0.1447	1.6	0.54	871.2	12.6	887.0	16.9	926.5	49.1	871.2	12.6
315	43815	4.3	13.8975	2.0	1.4671	2.3	0.1479	1.2	0.52	889.0	9.8	916.9	13.8	984.7	39.7	889.0	9.8
1377	131280	16.9	13.8971	2.3	1.4712	6.1	0.1483	5.7	0.92	891.4	47.1	918.6	37.0	984.7	47.4	891.4	47.1
445	87625	0.8	14.0163	1.0	1.4670	1.6	0.1491	1.2	0.78	896.1	10.4	916.9	9.6	967.3	20.4	896.1	10.4
377	56630	1.9	14.1573	1.5	1.4574	1.8	0.1496	1.1	0.59	899.0	8.9	912.9	10.8	946.9	29.7	899.0	8.9
357	110960	4.3	14.0480	1.2	1.4741	2.2	0.1502	1.9	0.84	902.1	15.7	919.8	13.3	962.7	24.1	902.1	15.7
122	51165	1.2	13.9913	3.3	1.4973	3.6	0.1519	1.4	0.40	911.8	12.1	929.3	21.8	971.0	67.1	911.8	12.1
158	140330	1.9	14.0649	1.6	1.5109	2.2	0.1541	1.6	0.69	924.1	13.3	934.8	13.7	960.2	32.9	924.1	13.3
419	85995	8.6	13.8326	1.7	1.5580	3.4	0.1563	3.0	0.87	936.2	25.7	953.7	21.1	994.2	34.6	936.2	25.7
173	56605	7.3	14.1350	1.4	1.5629	1.7	0.1602	1.0	0.59	958.0	8.9	955.6	10.5	950.1	27.9	958.0	8.9
233	46225	2.6	13.9229	2.8	1.6148	3.0	0.1631	1.1	0.36	973.8	9.9	976.0	18.8	980.9	56.8	980.9	56.8
290	69175	1.9	13.8741	3.0	1.6383	3.2	0.1649	1.2	0.36	983.7	10.6	985.1	20.3	988.1	61.3	988.1	61.3
181	72165	2.4	13.7557	1.5	1.6183	2.0	0.1615	1.3	0.66	964.9	11.7	977.3	12.4	1005.5	29.9	1005.5	29.9
395	153670	1.7	13.7092	1.7	1.6194	2.8	0.1610	2.3	0.80	962.4	20.1	977.8	17.6	1012.4	34.1	1012.4	34.1
102	45075	1.7	13.6187	2.1	1.6627	2.3	0.1642	1.0	0.44	980.2	9.1	994.4	14.5	1025.8	41.6	1025.8	41.6
169	58350	23.1	13.5581	2.5	1.6371	3.0	0.1610	1.6	0.52	962.2	13.9	984.6	18.7	1034.8	51.1	1034.8	51.1
343	81585	3.5	13.5510	2.0	1.7129	3.3	0.1683	2.7	0.80	1003.0	24.8	1013.4	21.4	1035.9	40.2	1035.9	40.2
195	143910	3.0	13.5288	1.6	1.7365	1.9	0.1704	1.2	0.60	1014.3	10.9	1022.2	12.5	1039.2	31.5	1039.2	31.5
149	153020	4.9	13.4958	3.1	1.7936	3.4	0.1756	1.4	0.42	1042.7	13.9	1043.1	22.3	1044.1	62.8	1044.1	62.8
118	34550	2.5	13.4821	2.6	1.7102	3.0	0.1672	1.4	0.46	996.8	12.6	1012.4	19.0	1046.1	53.3	1046.1	53.3
357	164815	3.7	13.4173	4.4	1.5548	6.2	0.1513	4.3	0.70	908.3	36.5	952.4	38.1	1055.9	88.7	1055.9	88.7
437	60685	1.2	13.4055	2.1	1.6421	3.9	0.1597	3.2	0.83	954.8	28.6	986.5	24.4	1057.6	42.9	1057.6	42.9
142	99225	4.4	13.3669	3.9	1.5829	5.0	0.1535	3.1	0.62	920.3	26.4	963.5	31.1	1063.4	79.3	1063.4	79.3
308	75850	1.7	13.3639	2.5	1.7659	8.1	0.1712	7.7	0.95	1018.5	72.8	1033.0	52.8	1063.9	50.7	1063.9	50.7
596	110020	22.1	13.2798	2.3	1.6626	5.0	0.1601	4.4	0.89	957.5	39.5	994.4	31.6	1076.6	45.6	1076.6	45.6
77	22050	2.7	13.2578	4.9	1.7902	5.0	0.1721	1.0	0.20	1023.8	9.5	1041.9	32.5	1079.9	98.0	1079.9	98.0
632	131425	2.9	13.1722	3.1	1.6320	7.3	0.1559	6.7	0.91	934.0	57.9	982.6	46.3	1092.9	62.1	1092.9	62.1
240	62105	1.3	13.1405	1.3	1.8856	1.7	0.1797	1.0	0.60	1065.4	9.8	1076.0	11.0	1097.7	26.4	1097.7	26.4
245	63750	3.3	13.0188	1.2	1.9102	2.3	0.1804	1.9	0.86	1069.0	19.1	1084.7	15.1	1116.3	23.4	1116.3	23.4

U	^{206}Pb	U/Th	^{206}Pb*	±	^{207}Pb*	±	^{206}Pb*	±	error	^{206}Pb*	±	^{207}Pb*	±	^{206}Pb*	±	Best age	±
67	14780	3.4	12.9971	3.6	1.8563	4.2	0.1750	2.2	0.51	1039.5	20.6	1065.7	27.8	1119.6	72.1	1119.6	72.1
273	131670	6.1	12.8997	3.0	1.8371	4.9	0.1719	3.8	0.79	1022.4	36.2	1058.8	32.0	1134.6	59.5	1134.6	59.5
242	166460	1.4	12.8364	1.2	1.9616	1.8	0.1826	1.4	0.76	1081.3	13.9	1102.4	12.3	1144.4	23.5	1144.4	23.5
132	44335	3.4	12.8266	2.8	2.0791	3.0	0.1934	1.0	0.34	1139.8	10.4	1141.9	20.3	1145.9	55.3	1145.9	55.3
129	55470	3.2	12.8114	1.6	2.1384	2.1	0.1987	1.4	0.66	1168.3	15.2	1161.3	14.9	1148.3	32.0	1148.3	32.0
268	62045	3.4	12.7971	1.1	2.1083	1.6	0.1957	1.2	0.74	1152.1	12.8	1151.5	11.3	1150.5	21.9	1150.5	21.9
204	92235	2.5	12.7927	1.5	2.0901	2.0	0.1939	1.3	0.66	1142.6	14.0	1145.6	13.9	1151.2	30.2	1151.2	30.2
471	162380	4.8	12.7808	1.7	1.9166	3.4	0.1777	3.0	0.87	1054.2	29.0	1086.9	22.9	1153.0	33.6	1153.0	33.6
94	39370	1.2	12.7387	2.8	2.0581	3.0	0.1901	1.0	0.34	1122.2	10.3	1135.0	20.3	1159.6	55.6	1159.6	55.6
92	31350	0.8	12.7128	2.3	2.0509	3.7	0.1891	2.9	0.78	1116.5	29.3	1132.6	24.9	1163.6	45.0	1163.6	45.0
351	119845	1.1	12.6918	1.9	2.1203	2.4	0.1952	1.6	0.65	1149.3	16.5	1155.4	16.7	1166.9	36.7	1166.9	36.7
241	72590	2.5	12.6819	1.0	2.1751	1.4	0.2001	1.0	0.70	1175.7	10.7	1173.1	9.9	1168.4	20.0	1168.4	20.0
220	148075	4.8	12.6763	2.1	2.0923	4.8	0.1924	4.3	0.90	1134.1	44.9	1146.3	33.0	1169.3	41.6	1169.3	41.6
772	121430	4.2	12.6491	2.6	1.8997	5.4	0.1743	4.8	0.87	1035.7	45.5	1081.0	36.2	1173.5	52.3	1173.5	52.3
70	9760	1.8	12.6067	2.6	1.7891	3.2	0.1636	1.8	0.57	976.6	16.4	1041.5	20.7	1180.2	51.6	1180.2	51.6
185	50300	3.0	12.5611	1.8	2.1231	2.7	0.1934	2.0	0.75	1139.9	21.0	1156.3	18.6	1187.3	35.4	1187.3	35.4
538	181480	2.3	12.5352	1.7	2.0457	2.4	0.1860	1.6	0.69	1099.6	16.6	1130.9	16.3	1191.4	34.3	1191.4	34.3
184	64655	1.8	12.5331	1.6	2.1877	1.9	0.1989	1.0	0.54	1169.2	10.7	1177.1	13.0	1191.8	31.0	1191.8	31.0
216	29240	2.9	12.4548	1.6	1.8255	4.6	0.1649	4.3	0.94	984.0	39.4	1054.7	30.1	1204.1	30.5	1204.1	30.5
648	64865	3.0	12.3798	3.8	2.0693	5.0	0.1858	3.3	0.66	1098.5	33.7	1138.7	34.5	1216.0	74.2	1216.0	74.2
153	106115	2.2	12.3252	3.2	2.1904	3.7	0.1958	1.8	0.49	1152.7	19.0	1178.0	25.8	1224.7	63.5	1224.7	63.5
260	72780	2.3	12.2890	2.3	2.3024	2.5	0.2052	1.0	0.39	1203.3	11.0	1213.0	18.0	1230.5	45.7	1230.5	45.7
451	296585	23.9	12.2503	3.3	2.2196	3.7	0.1972	1.6	0.43	1160.3	17.1	1187.2	26.0	1236.7	65.5	1236.7	65.5
323	93820	2.1	12.1228	3.7	2.2935	4.6	0.2017	2.7	0.59	1184.2	29.2	1210.3	32.2	1257.1	71.8	1257.1	71.8
539	226165	4.5	12.0447	1.2	2.3000	1.6	0.2009	1.0	0.64	1180.3	10.8	1212.3	11.0	1269.8	23.2	1269.8	23.2
313	160110	8.0	12.0110	1.3	2.6135	3.0	0.2277	2.7	0.89	1322.3	31.8	1304.4	21.9	1275.2	26.1	1275.2	26.1
195	52755	1.8	11.9707	2.0	2.3492	2.7	0.2040	1.9	0.69	1196.6	20.2	1227.3	19.2	1281.8	38.2	1281.8	38.2
366	100525	3.8	11.9134	5.9	2.2525	7.2	0.1946	4.1	0.58	1146.4	43.5	1197.6	50.5	1291.1	114.1	1291.1	114.1
205	102540	2.9	11.7945	2.1	2.5124	3.4	0.2149	2.6	0.77	1255.0	29.8	1275.6	24.5	1310.6	41.5	1310.6	41.5
205	102540	2.9	11.7945	2.1	2.5124	3.4	0.2149	2.6	0.77	1255.0	29.8	1275.6	24.5	1310.6	41.5	1310.6	41.5
248	109930	1.7	11.7158	2.9	2.4425	8.9	0.2075	8.4	0.94	1215.7	93.0	1255.2	64.1	1323.6	56.8	1323.6	56.8
370	100165	1.7	11.4239	2.6	2.4966	7.4	0.2069	7.0	0.93	1212.0	76.8	1271.0	54.0	1372.3	50.8	1372.3	50.8
134	85690	2.8	11.3613	1.8	2.7651	2.3	0.2278	1.4	0.63	1323.2	17.0	1346.2	16.8	1382.9	33.6	1382.9	33.6
408	41555	3.2	11.1950	4.2	2.4862	5.2	0.2019	3.2	0.61	1185.3	34.4	1268.0	37.9	1411.1	79.5	1411.1	79.5
667	158940	8.2	11.1108	3.9	2.6701	4.3	0.2152	1.7	0.40	1256.3	19.6	1320.2	31.8	1425.6	75.3	1425.6	75.3
257	85185	2.1	7.7723	3.4	6.5784	3.6	0.3708	1.0	0.28	2033.3	17.4	2056.5	31.5	2079.8	60.4	2079.8	60.4
157	350120	2.5	4.0278	2.1	21.5463	2.3	0.6294	1.0	0.43	3147.3	24.9	3163.5	22.7	3173.8	33.6	3173.8	33.6

Table 1. U-Pb detrital zircon data obtained from 86 zircons, Sample LB-18, Late Triassic, La Ballena, Sierra de Salinas

3. The early mesozoic record in central and northeastern Mexico

The Mesa Central in central to northeastern Mexico is a plateau situated between the Sierra Madre Oriental to the East and the Sierra Madre Occidental to the west. The Mesozoic rocks of the Mesa Central and Sierra Madre Oriental provinces, are mostly covered by Cenozoic sedimentary and volcanic successions and the more expanded Mesozoic outcrops in this region are cretaceous limestone. Triassic and Lower Jurassic rocks are subordinated and occur regularly in uplifted areas. The Late Jurassic-Cretaceous cover consisting mostly of limestone and marls in this region shows compressive deformation produced during the Laramide orogeny and is frecuently detached from the underlying Triassic-Lower Jurassic succession, mostly composed of siliciclastic and volcanic rocks. There are in the Mesa Central three widely recognized Triassic to Middle Jurassic stratigraphic units (Barboza-Gudiño et al., 1998, 1999): (1) Upper Triassic Submarine fan deposits in Central Mexico (Zacatecas Formation), (2) A Lower to Middle Jurassic volcanic succession (Nazas Formation, Pantoja-Alor, 1972), and (3) A Middle Jurassic fining upward succession of red beds that general change gradually from conglomerate or breccias on their basis to sandstone and mudstone on the top, changing transitionally into Oxfordian transgressive shallow marine limestone. In the Sierra Madre Oriental, The corresponding Late Triassic-Middle Jurassic stratigrapy consists of three units, comparable in age but not in their facies with the units exposed in the Mesa central: (1) Late Triassic rocks interpreted as a fluvial facies, exposed in southern Nuevo León and Tamaulipas, and defined as El Alamar Formation (Barboza-Gudiño et al., 2010), (2) Lower Jurassic red beds and interlayered volcanic and volcanoclastic deposits, defined as La Boca Formation (Mixon et al, 1959) or Hizachal-Formation (Imlay et al., 1948, Carrillo-Bravo, 1961), (3) Finnaly, La Joya Formation (Mixon et al, 1959), consisting of breccias or conglomerates and red sandstones, representing a widely identified erosional unconformity. Such propossed stratigraphic division is a result of field observation and description of sedimentary facies based on lithological-sedimentological studies supported by data obtained by most of the previously described analytical methods (Figure 4, 5).

3.1 Upper Triassic Submarine fan deposits in Central Mexico (Zacatecas Formation)

Upper Triassic marine rocks in the Mesa Central province, were first described by Burckhardt and Scalia (1905) at Arroyo La Pimienta in the vicinity of Zacatecas city (Figure. 1), who described a light metamorphosed succession composed of greenstone, sandstone and alternating shale or "phylithe" containing a triassic fauna which include several ammonites, and bivalves. These rocks were first named "Triásico de Zacatecas" (Gutierrez-Amador, 1908) and are currently known as the "Zacatecas Formation", (Carrillo-Bravo 1968 *in* Silva-Romo et al., 2000, Martínez-Pérez., 1972, Carrillo-Bravo 1982). Outcrops of comparable rocks were later reported near La Ballena Zacatecas (Cantú Chapa, 1969), Charcas and Sierra de Catorce, San Luis Potosí (Martínez-Pérez, 1972). The age of the strata exposed in this localities was supported by fauna of amonoids in La Ballena or Sierra de Salinas (Gómez-Luna et al., 1998) and amonoids (Cantú-Chapa, 1969 and Gallo-Padilla et al., 1993) and conodonta (Cuevas Pérez., 1985) in the Charcas area, remaining unknown in the Sierra de Catorce and other outcrops in northern Zacatecas and northwestern San Luis Potosí because a lack of fossils.

With minor differences between all studied localities, the Zacatecas Formation consists of a siliciclastic succession, mostly composed of interstratified sandstone, siltstone, shale and conglomeratic sandstone. At Arroyo La Pimienta, Zacatecas, the Triassic Succession consists of alternating dark gray to brown shale and thin to middle bedded sandstone, the upper part of the exposed sequence, consists of fossiliferous black shale or phylite with quartzite lenses, at this locality, Centeno-García (2005) reported ancient MORB remnants underlying the Triassic succession. In La Ballena, at the border zone between Zacatecas and San Luis

Potosí states, The Zacatecas Formation, named also locally La Ballena Formation (Centeno-García and Silva-Romo, 1997), consists of interstratified sandstone, siltstone, shale and conglomeratic sandstone. At Sierra de Charcas, west of Charcas, San Luis Potosí, in La Trinidad Anticlinorium and several minor outcrops to the north in the Santa Gertrudis area, (Figure 1), the triassic succession consists of turbiditic sandstones, conglomeratic sandstones, and greywacke, alternating with siltstone and shale. The greywacke and sandstone beds contain internally graded bedding, commonly showing partial developed Bouma sequences, load and groove casts are the most common sole marks, as well as slump deposits and wildflysh. The succession at Sierra de Catorce in northern San Luis potosí consists of finely laminated shale and intercalated thin siltstone and sandstone layers. There are no reports of Triassic fossils in this locality, and an older age has been also suggested by a possible Late Paleozoic flora (Franco-Rubio, 1999) and Late Paleozoic spores (Bacon, 1978). Finally intensely deformed and poorly understood successions consisting of probable triassic sandstone and shale containing ophiolitic rocks and older exotic blocks, are known as Taray Formation in northern Zacatecas (Córdoba-Méndez, 1964), El Chilar Complex, Queretaro, recently dated as a possible Late triassic deposit (Davila-Alcocer at al., 2008) and other outcrops in the Sierra de Guanajuato and Durango.

The most recent studies from triassic rocks in western San Luis Potosí and Zacatecas include sedimentologic, stratigraphic, geochronologic and tectonic studies (Centeno-García and Silva-Romo,1997; Silva-Romo et al., 2000; Hoppe et al., 2002, Bartolini et al., 2001, Barboza-Gudiño et al., 2010), interpreting all Triassic marine successions in the Mesa Central, as part of a submarine fan, named the "Potosí fan" by Centeno-García (2005). All facies are compatible with those of a submarine fan, including facies "A" (after Mutti and Ricci Lucchi, 1972) that represent channels, facies "B" and "C", representing channel margins and facies "D", "E" "F" and "G" (suprafan lobe, levee, and inter-channel flats), corresponding in the Charcas outcrops to a midfan or suprafan zone. The most common facies associations in Real de Catorce are lithofaces "D", "E", and "G". in La Ballena the lithofacies succession , interpreted as middle to lower fan include well developed "C" and "B" facies, "A" facies in La Ballena correspond to channel margins, suprafan lobes and channel environments, respectively.

There are no known exposures of the base of the Zacatecas Formation in the Mesa Central, but the presence of oceanic crust supposedly underlying the Zacatecas Formation at the vicinity of Zacatecas city allow to interpret a remnant basin for the latest Paleozoic and Early Mesozoic time, floured by oceanic crust at the western margin of Pangea, where some of the earliest deposits of the Potosí Fan (Zacatecas Formation), occurred during the Middle to Late Triassic time. Eastward, the first deposits of the Potosí Fan, also Middle to Late Triassic in age, rest hypothetical, over an older, Precambrian-Paleozoic crust, like the Oaxaquia block (Ortega-Gutierrez et. al., 1995), as indicated by upper crustal xenoliths contained in volcanic rocks of the same region. The thickness is also very difficult to estimate, because the strongly deformed strata and the previously mentioned lack of exposures incluiding their base. As a structural thickness of this rock body which include a considerable structural increase, can be mentioned the Tapona-1 Well drilled by PEMEX in the Sierra de la Tapona, northwest of Charcas, where the total depth of the well represent Triassic turbidites of the Zacatecas Formatio, without reaching the base (PEMEX internal report, cited in Tristán-González et al., 1995).

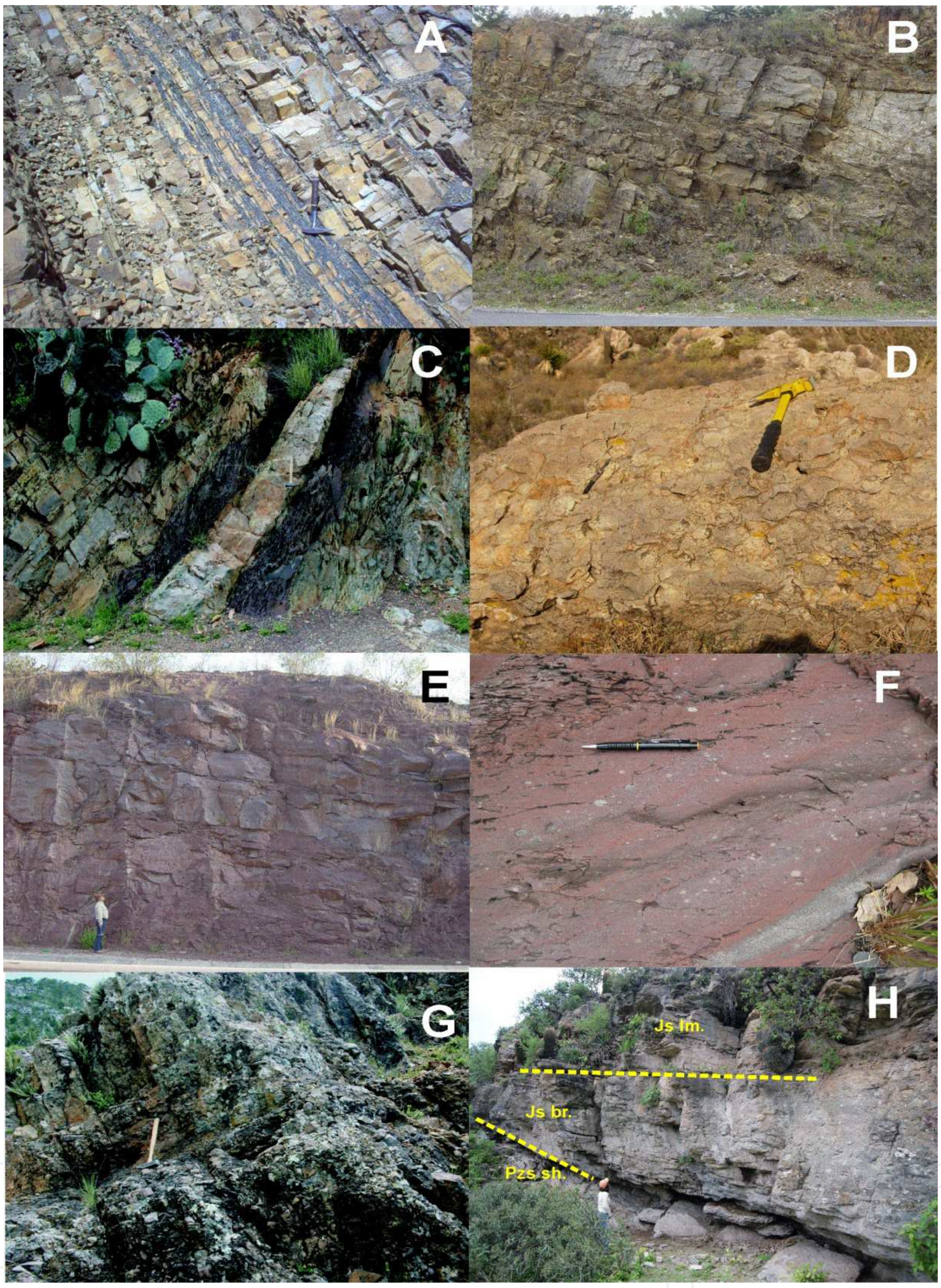


Fig. 4. A. Triassic turbidites of the Zacatecas Formation (Charcas), B. Conglomeratic sandstones in El Alamar Formation (San Marcos), C. Lower Jurassic greenstone, quarzite and red to yellow mudstones, Capas Cerro El Mazo (Real de Catorce), D. Spherulitic Rhyolite, Nazas Formation (Sierra de San Julián), E. Lower Jurassic red sandstone, La Boca Formation (Huizachal), F. Distorted accretionary lapilli in epiclastic layers of La Boca Formation (La Boca Canyon), G. Polymictic breccia, La Joya Formation (San Marcos), H. La Joya Formation (Js Br.) overlies Paleozoic schist and phylites (Pz sh.), by no deposition of Triassic and Jurassic red beds, the breccias change gradually upwards into shallow marine limestone of the Upper Jurassic Novillo Formation, an equivalent of the basal part of the Zuloaga Formation (Aramberri)

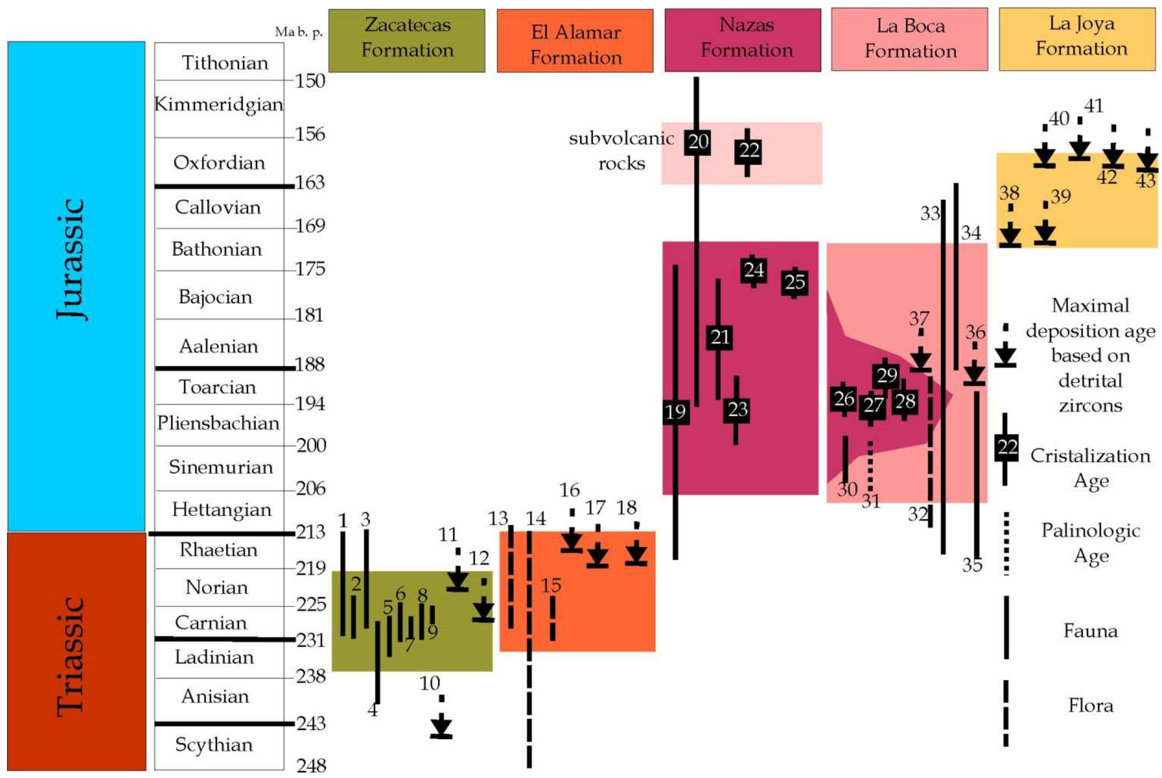


Fig. 5. Paleontologic, palinologic and isotopic ages of pre-Oxfordian units from Central and northeastern Mexico: Data and sources: 1. *Avicula hofmanni, Cassianella (Burkhardtia)* aguilerae, *Halovia austriaca* mojsisovics, *Palaeoneilo aguilerae*. (Zacatecas, Burkchardt and Scalia, 1905); 2. *Juvavites* sp., *Pleurotoma* sp.(Zacatecas, Gutierrez-A., 1908); 3. *Pseudomonotis* sp., (Zacatecas, Maldonado-K.,1948); 4. *Berichitidae Spath*, 1934 (La Ballena, Gallo-P. et al., 1993); 5. *Clionitidae* Tozer, 1994, *Trachiceratidae* Haug, 1994 (La Ballena, Gómez-L. et al., 1997); 6. *Sirenites* sp. (La Ballena, Chavez-A., 1968); 7. *Juvabites* sp. (Charcas, Cantú-Ch., 1968); 8. *Aulacoceras* sp. (Charcas, Gallo-P. et al., 1993); 9. *Neogondolella polygnatiformis, Epigondolella Primitia* (Charcas, Cuevas-P., 1985); 10. This work (La Ballena); 11. Charcas (Barboza-Gudiño et al., 2010); 12. Real de Catorce (Barboza-Gudiño et al., 2010); 13. *Podosamites* sp. (Source of Novillo C., Mixon et al, 1959); 14. *Araucarioxylon* (La Boca C., Mixon et al, 1959); 15. *Laurozamites yaqui* (reported as "*Pterophyllum fragile*" by Mixon et al, 1959), *Ctenophyllum braunianum* (reported as "*Pterophyllum inaequale*", by Mixon et al., 1959), "*Elatocladus ex* gr. *Carolinensis* (reported as "*Cephalotaxopsis carolinensis*" by Mixon et al., 1959), (Source of Novillo C., Weber, 1997); 16. San Marcos, N.L. (Barboza-Gudiño et al., 2010); 17. Cañón de La Boca (Barboza-Gudiño et al., 2010); 18. San Marcos, N.L. (Barboza-Gudiño et al., 2010); 19-20. Rb-Sr, (w), N Zacatecas, (Fries & Rincon-O, 1965); 21.K-Ar,(h),Rodeo, (López-I., 1986); 22. U-Pb, (zr), Caopas (Jones et al, 1995); 23. 40Ar/Ar39(pl), Villa Juárez (Bartolini & Spell, 1997); 24. U-Pb (zr), Real de Catorce (Barboza-Gudiño et al., 2004); 25. U-Pb (zr) Charcas (Zavala-Monsivais et al., in press.); 26. U-Pb (zr) Aramberri (Barboza-Gudiño et al., 2008); 27. U-Pb(zr), Huizachal C. (Fastovsky et al., 2005); 28. U-Pb (zr), Huizachal (Zavala-M. et al., 2009); 29. U-Pb (zr), Aramberri (Zavala-M. et al., 2009); 30. *Bocatherium mexicanum*, Huizachal C. (Clark et al, 1994); 31. Palinomorpha, La Boca C. (Rueda-Gaxiola et al., 1993); 32. Williamsonia netzahualcoyotl (Carrillo-Bravo, 1961); 33. Pterosaurio, Huizachal Canyon., *Sphenodon* sp.. Nov., Huizachal (Reynoso-Rosales, 1992); 35. *Cynosphenodon huizachalensis*, Huizachal (Reynoso-Rosales (1996); 36-41. Huizachal (Rubio and Lawton, 2011); 42. Miquihuana (Barboza-Gudiño and Zavala-Monsivais, 2011); 43. Real de Catorce (Barboza-Gudiño and Zavala-Monsivais, 2011).

The age of the Zacatecas Formation is well established in Zacatacas, La Ballena and Charcas, through their fossil fauna (Figure 4). In The Sierra de Catorce, Sierra de Las Teyra and several other minor outcrops in the Presa de Santa Gertrudis area, aren't any byostratigraphic ages available because a Lack of fossils. For age determination in the Sierra de Catorce, Barboza-Gudiño et al. (2010) provided a maximal age of deposition of ca. 230 Ma (Figure, 5), consistent with a previously interpreted Late Triassic age (Martínez-Pérez, 1972, López-Infanzón, 1986, Cuevas-Pérez, 1985, Barboza-Gudiño et al., 1999), based only on stratigraphic position and lithological similarities.

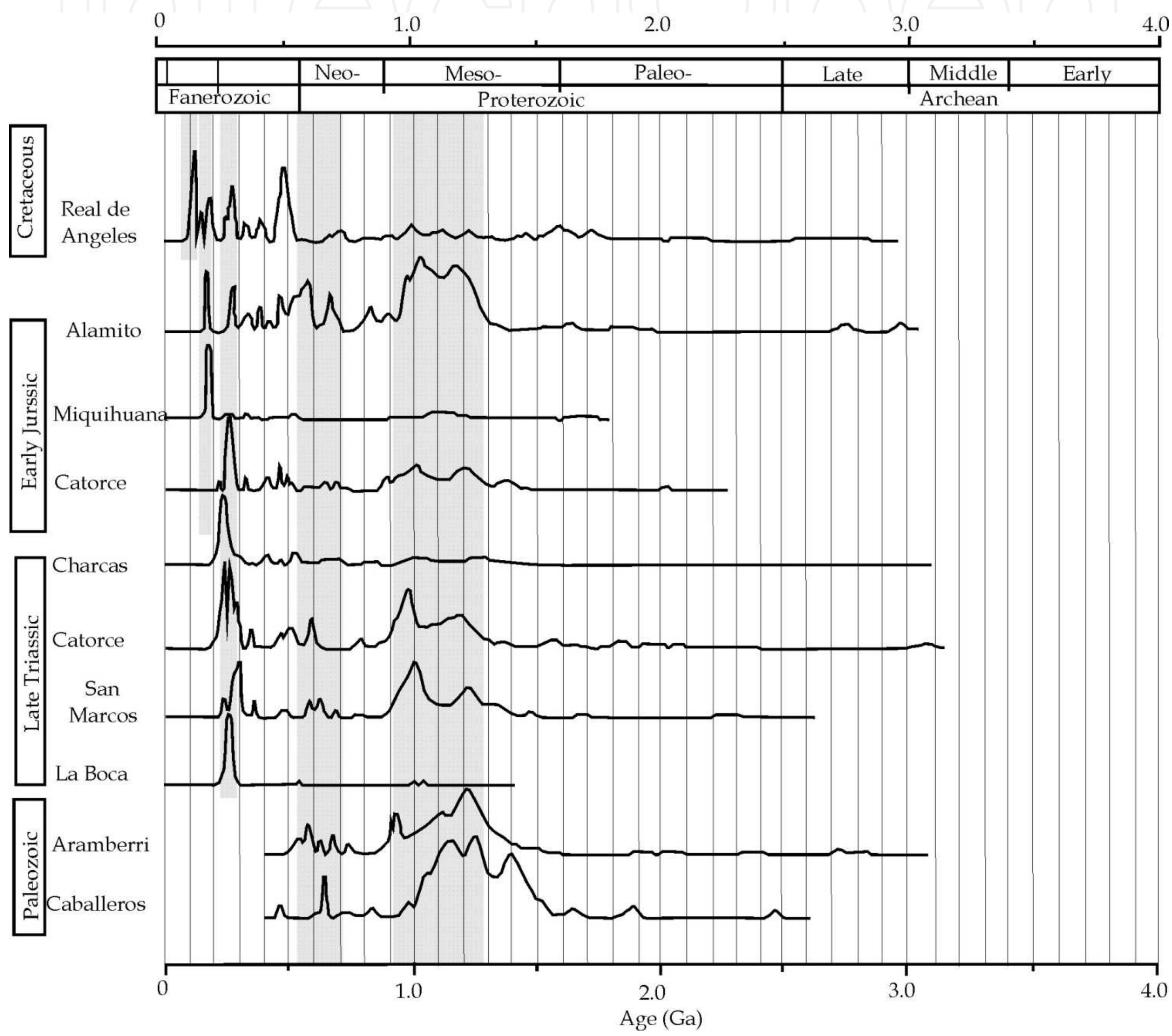


Fig. 6. Probability curves of several published detrital zircon results from Paleozoic and Mesozoic rocks from northeastern Mexico (Venegas-Rodríguez et al., 2009; Barboza-Gudiño et al., 2010; Barboza-Gudiño et al., 2011; Barboza-Gudiño & Zavala Monsiváis, 2011).

Figure 5 include results from two detrital zircon analyses from samples collected in the Zacatecas Formation from Charcas and Real de Catorce; these results were previously reported by Barboza-Gudiño et al (2010). The results are plotted as age-probability curves (Ludwig, 2003) besides results from other stratigraphic units discussed also in this chapter. A maximal depositional age between 225-230 Ma for sample collected in the Sierra de

Charcas, correspond also to the Late Triassic similar to the sample collected in the Sierra de Catorce. Both samples show notable contributions of a Permo-Triassic zircons (245-280 Ma), which correspond with the east Mexico Permo-Triassic magmatic arc, that yield K-Ar and Rb-Sr ages from 284 to 232 Ma (Torres et al., 1999, Dickinson and Lawton, 2001). Paleozoic ages between 420-467 Ma, correspond probably to Ordovician-Silurian magmatic rocks described in peri-Gondwanan terranes of Mexico like the Acatlán Complex (Miller et al., 2007) or as detrital zircon age populations present in the Granjeno Schist in northeastern Mexico (Nance et al., 2007, Barboza-Gudiño et al., 2011) or El Fuerte Formation in Sinaloa (Vega-Granillo et al., 2009). Populations corresponding to the pan-African (700-500 Ma) and Grenvillian (900-1300 Ma) events, as well as subordinate Paleoproterozoic to Archean zircons are also present in both samples.

Sediment-petrographic studies were also performed to interpret provenance by point counting in the sandstones of the Zacatecas Formation, the results, plotted in the provenance diagrams of figure 2, suggest continental block and recycled orogen provenances. Geochemical results (Barboza-Gudiño et al., 2010) are indicative of provenance from igneous rocks, accord to the Chondrite normalized REE, showing a negative Eu anomaly, formed by intracrustal differentiation incluiding plagioclase fractionation. There is a notable similarity with LREE enrichment and a flat HREE sector in all Triassic samples. The relations Th/Sc ≈ 1 and Zr/Sc ≈10-100 are product of zircon addition, indicative of sediment recycling, as typical for trailing edge turbidites in a passive margin (McLennan et al., 1993). In addition, the initial ε_{Nd} ratios as reported by Centeno-García and Silva-Romo (1997) in sandstones collected in La Ballena and Zacatecas, are -5.2 and -5.5 respectively, and are indicative of an old upper continental crust provenance, as well as the Nd-model ages of 1.3 to 1.6 Ga in agreement with a model of source in an old continental block at the east-northeast of the region, like the Proterozoic Oaxaquia microcontinent.

3.2 Upper Triassic fluvial succession in the Sierra Madre Oriental: El Alamar formation

The Upper Tri assic succession of continental strata expossed in the Sierra Madre Oriental was defined as El Alamar Formation by Barboza-Gudiño et al. (2010). Previously Upper Triassic and Lower Jurassic rocks in northeastern Mexico were referred as the Huizachal Group (Mixon et al., 1959), consisting of the Upper Triassic to Lower Jurassic La Boca Formation and the unconformable overlying La Joya Formation of Middle to Late Jurassic age. After Barboza's definition (op.cit.) of the only Triassic El Alamar Formation, La Boca Formation in consequence consists of a red beds and interlayered volcanic and volcanoclastic succession Early to Middle Jurassic in age. A detailed description of the evolving stratigraphic nomenclature of the early Mesozoic units in the region is given by Barboza-Gudiño et al., (2010).

The name El Alamar Formation is derived from El Alamar Canyon in the Sierra de Pablillo, Nuevo León, where the proposed unit stratotype and type section are located at El Alamar Canyon, were the exposed sequence consists of more than 350 m of mostly gray and brawn-red colored conglomeratic sandstones, siltstones and mudstones. In the Huizachal-Peregrina anticlinorium in Tamaulipas incomplete sections of El Alamar Formation rests unconformably on Paleozoic metamorphic, sedimentary and magmatic rocks. The best exposures are Alamar canyon in the Sierra de Pablillo and the San Marcos area south of

Galeana, Nuevo León, along federal highway 58 (San Roberto-Linares). El Alamar Formation is the oldest unit exposed in the Galeana region and there are no exposures of their basis or any older strata.

El Alamar Formation consist of thick bedded, medium- to coarse-grained arkosic sandstone, usually containing basal conglomeratic lag horizons, changing upwards into finely laminated sandstones-siltstones and interlayered mudstones. The most abundant primary structures are trough cross-beds and channel scours, tabular burrows are common in fine-grained facies. There is a notable abundance of petrified wood (possible *Araucarioxylon* sp.), commonly associated with conglomerate and coarse grained sandstone facies, which represent channel and channel bar deposits. Several decimeter cylindrical burrow casts interpreted as possible rhizoliths or probable lungfish burrows are associated with the siltstone and mudstone facies, which represent floodplain deposits. These lithologies represent upward -fining cycles, tens of meters in thickness, and are interpreted as basal channels overlain by sand flats and overbank deposits, formed in low sinuosity streams and braided channels. Michalzik (1991) interpreted this cyclic deposition as a Donjek type fluvial system, and recognized different lithofacies after codes of Miall (1977): conglomerate facies (Gm, Gt), trough and planar cross-beds as well as horizontal-bedded coarse sandstone (St, Sp, Sh), horizontal bedded and plannar cross-bedded sandstone (Sh, Sl), laminated and massive siltstone facies (Fl, Fm), and mudstone to siltstone facies with carbonate concretions (Fm, P).

The facies associations recognized in El Alamar Formation correspond to proximal alluvial fan, braided stream and distal meandering stream deposits. The Triassic strata in Tamaulipas unconformably overlie Paleozoic strata or Precambrian-Paleozoic basement and are overlain by Jurassic redbeds of La Boca Formation, during in Nuevo Leon their base is not exposed and there is no evidence of deposition of the Lower Jurassic La Boca Formation in this area, where El Alamar Formation is in turn unconformably overlain by the Middle to Upper Jurassic La Joya Formation. The El Alamar Formation is absent in the Aramberri-Miquihuana area in southern Nuevo León and Tamaulipas where Jurassic red beds and volcanic rocks or in some places Upper Jurassic Limestones rest on Paleozoic metamorphic rocks.

Mixon et al. (1959) reported in the lower unit of their Huizachal Group or actual El Alamar Formation, a floral assemblage of Late Triassic age, reinterpreted by Weber (1997)suggesting that this flora is well indicative of the Late Triassic but more precisely of a Carnian and probably Norian age. A Late Triassic age is also in agreement with an Early Triassic maximal age of deposition (245 Ma), accord to detrital zircon geochronology. The El Alamar Formation is thus of the same age as the Late Triassic Zacatecas Formation, which represents the marine counterpart of the El Alamar fluvial system. We show below that they also have very similar provenance characteristics.

3.3 Lower to Middle Jurassic volcanic arc in central and north-central Mexico: Nazas formation

Volcanic and volcano-sedimentary successions rest unconformable on the Triassic Zacatecas Formation and are known in north-central to northeastern Mexico as the Nazas Formation (Pantoja-Alor, 1972). These volcanic rocks were assigned to the Late Triassic-Lower Jurassic volcanic arc, related to the active continental margin of western North America (Blickwede, 2001; López-Infanzón, 1986, Grajales-Nishimura et al., 1992; Jones et al., 1995; Bartolini, 1998; Bartolini et al., 2003; Barboza-Gudiño et al., 1998, 1999, 2004). The type locality of the Nazas Formation, as defined by Pantoja–Alor (1972) is the Cerritos Colorados area west of Villa Juarez, in northern Durango. The most common volcanic rocks in the type locality are rhyolitic ash flow tuffs including well preserved gray to green colored ignimbrite horizons, alternating with red-brown epiclastic materials.

In other localities of the Mesa Central, the volcanic products of the Nazas Formation are intermediate to felsic. In the Sierra de San Julián, in northern Zacatecas, Blickwede (2001) describes a 1,000 m thick volcanic succession consisting of lava flows, air-fall and ash-flow tuffs, and lahars. In the Caopas-Rodeo uplift, porphyritic rhyolite with quartz and sanidine phenocrysts of the Caopas schist and the andesitic Rodeo formation, first considered, to be pre-Jurassic because of their strongly deformed aspect (de Cserna, 1956, Córdoba-Méndez, 1964), are coeval with the Nazas Formation accord to later geochronologic studies (López-Infanzón, 1986, Jones et al., 1995, (Table 2).

In western San Luis Potosí, volcanic successions including andesitic and dacitic lava flows and volcanic breccias, as well as rhyolitic domes and ash flow tuffs, are exposed in the Sierra de Catorce, Charcas and Sierra de Salinas or La Ballena area, they rest on Triassic turbiditic layers of the Zacatecas Formation or local in Real de Catorce, on the marginal marine beds of the Lower Jurassic informal unit "Capas Cerro El Mazo" (Barboza-Gudiño et al., 2004). The Capas Cerro el Mazo unit consists of conglomeratic sandstone and medium- to coarse-grained litharenites with fragments of plants, and gray to green and red to purple siltstone and mudstone layers interfingered with volcanic greenstones at the base of the Nazas Formation, which include dacitic and rhyolitic pyroclastic and porphyritic rocks. Detrital zircon geochronology in this succession support a maximum Early Jurassic depositional age and three primary sources of detrital zircons that include Grenvillian (~900-1200 Ma) and Pan-African basement rocks (~500-700 Ma) as well as the Permo-Triassic magmatic arc (~245-280 Ma). Petrographic studies indicate a recycled orogen and continental block provenance. Barboza-Gudiño et al. (2004) reported U-Pb isotopic analyses of zircon for a rhyolite in the upper part of the succession of the Sierra de Catorce, yielded an age of 174.7 ± 1.3 Ma.

In the Sierra de Salinas, basaltic-andesitic fluidal, porphyritic lava is the dominant rock type, composed of probable hornblende phenocrysts, scarce pyroxene, olivine and abundant acicular plagioclase as the main component of the groundmass. In the Sierra de Salinas and some outcrops of the Sierra de Charcas, the lavas are brecciate at the base of the andesitic flows, arranged in a "*puzzle structure*", like an autoclastic breccia, related to a flow front or basal breccias, engulfed by igneous material of the same composition. General, the most common rocks in the Sierra de Charcas are andesitic to rhyolitic pyroclastic products, Including breccias, lapilli tuffs, and ash flow tuffs.

The volcanic successions described here are part of the Early Jurassic volcanic arc, related to the ancient active margin of Pangea. The available ages (Tables 2) indicate that the volcanic arc was probably active for a period of 40 Ma during the Jurassic. The volcanic rocks of the described localities correlate with the Nazas Formation of northern Durango and Zacatecas and, therefore, represent a key unit for the stratigraphic subdivision, and paleogeographic and paleotectonic interpretations of north and northeastern Mexico.

Locality	State	Rock type	Method	Material dated	Age (Ma)	Source
Caopas	Zacatecas	meta-rhyolitic sub-volcanic	Rb-Sr	whole rock	195±20	Fries & Rincon-O. 1965
Caopas	Zacatecas	meta-rhyolitic sub-volcanic	Rb-Sr	whole rock	156±40	Fries & Rincon-O. 1965
Caopas	Zacatecas	meta-andesite (Rodeo Form.)	K-Ar	hornblende	183±8	López-Infanzón, 1986
Caopas	Zacatecas	meta-rhyolitic sub-volcanic	U-Pb	zircon	158±4	Jones et al., 1995
Villa Juárez	Durango	rhyolite	$^{40}Ar/^{39}Ar$	plagioclase	195.3±5.5	Bartolini & Spell, 1997
Catorce	San Luis Potosí	rhyolite	U-Pb	zircon	174.7±1.3	Barboza-Gudiño et al., 2004
Charcas	San Luis Potosí	rhyolitic ignimbrite	U-Pb	zircon coherent gr.	176.8 +4.9/-1.7	Zavala et al. In press
Huizachal	Tamaulipas	rhyolitic ash flow	U-Pb	zircon	189.0±0.2	Fastovsky et al., 2005
Aramberri	Nuevo León	rhyolitic ignimbrite	U-Pb	zircon	193.1±0.3	Barboza-Gudiño et al., 2008
Huizachal	Tamaulipas	rhyolite	U-Pb	zircon	194.1 +4.1/-4.5	Zavala-M. et al., 2009
Aramberri	Nuevo León	rhyolitic ignimbrite	U-Pb	zircon	189.5 ±3.8	Zavala-M. et al., 2009

Table 2. Selected isotopic ages of Jurassic volcanic rocks from the Nazas Formation in north-central to northeastern Mexico. For location of the areas see figure 1.

In Nuevo León state, volcanic rocks are exposed a few kilometers north of Aramberri, consisting of ignimbrites, volcanic breccias and tuffs of intermediate to felsic composition, which overlie Paleozoic schist and unconformable underlie transgressive Upper Jurassic strata. An U-Pb zircon age determination in a rhyolitic-rhyodacitic ignimbrite yields an essentially concordant age of 193.1 ± 0.3 Ma.

Lower Jurassic volcanic rocks are also exposed at Huizachal Valley, Tamaulipas (Jones et al., 1995, Fastovsky et al., 2005) and the Miquihuana-Bustamante area (Bartolini et al., 2003). In the Huizachal Valley the volcanic andesitic and rhyolitic rocks represent the basal part of the exposed Mesozoic succession, underlying and partially intruding Lower Jurassic red beds of La Boca Formation or more precisely, at this locality as in all exposures in Nuevo

León and Tamaulipas, the volcanic rocks are considered part of the La Boca Formation and occur in form of rhyolitic domes with steeply dipping flow bands resulting from magma injection, flow-like bands and lava flows or lobes with spherulitic structures and associated ash flow tuffs. Zircon grains from a pyroclastic flow at this locality were dated by U-Pb at 189 ± 0.2 Ma (Fastovsky et al., 2005) as well as new ages from Zavala-Monsivais et al. (2009).

Geochemical analysis from intermediate to felsic rocks shows a calc-alkaline character. Trace element abundances characteristic of rocks generated by subduction processes (Barboza-Gudiño et al, 2008), and generally related to the enrichment of large-ion lithophile elements (e.g., Rb, Ba, K) and light rare earth elements (e.g., La, Ce) in fluids and melts released from the subducting plate to the overlying mantle. The trace element patterns shown in the normalized multi-element diagram are a strong evidence for an origin in a continental arc setting. Rare earth element (REE) abundances are enriched in light REE relative to heavy REE and have a relatively steep slope for the LREE (La-Eu) and a flat pattern for the HREE (Gd-Lu). The most evolved samples (rhyolites), show negative Eu-anomalies, indicative of plagioclase fractionation.

The general features of the exposed volcanic sequences, the petrography of the diverse materials and the geochemical data, support the conclusion that all the studied pre-Oxfordian volcanic rocks originated in a continental arc. Our analyses provide a general idea of the compositional variations among the sequences or localities, which, however, are common in volcanic arcs composed of different volcanic centers. These variations also document the changes in composition of all volcanic products during magmatic evolution in space and time. The following observations are evidence for an origin of these rocks in a continental volcanic arc. The volcanic units are unconformably overlain by Upper Jurassic red beds of the La Joya Formation and shallow marine limestone of the Zuloaga Formation.

3.4 Lower Jurassic Fluvial, epiclastic and volcanogenic deposits (La Boca Formation)

Imlay et al. (1948) proposed the name Huizachal Formation for redbeds exposed in the Huizachal valley, 20 km southwest of Ciudad Victoria, Tamaulipas unkonformably underlying oxfordian limestone. Mixon et al. (1959) separated two units of redbeds in the Huizachal-Peregrina anticlinorium and defined La Boca Formation as the older unit and the younger, La Joya Formation, which represent an erosional unconformity as a basal conglomerate for the transgressive Callovian-Oxfordian limestones and evaporates coeval with opening of the Gulf of Mexico basin. Both units were defined by the same authors as the Huizachal group.

The La Boca Formation is well exposed in the Huizachal Peregrina Anticlinorium (Carrillo-Bravo, 1961; Rueda Gaxiola et al., 1993, 1999), the Miquihuana-Bustamante area in Tamaulipas and near Aramberri, Nuevo León. In the Huizachal-Peregrina Anticlinorium consists of ca. 1500 m of red sandstones, siltstones and mudstones, as well as interlayered polymictic matrix supported conglomerates and conglomeratic sandstones. The sandstones and siltstones are well stratiefed in medium sized beds, with internal fine lamination. Conglomeratig sandstones are thick bedded, with well developed curved cross lamination and pelitic rocks occur mostly as massive sized beds.

La Boca Formation also interfinger with volcanogenic deposits at several localities, , including Huizachal and La Boca Canyons and contains a fossil assemblage of vertebrate fauna, which allows assignment to an Early to Middle Jurassic age for red beds outcropping in the Huizachal Canyon (Clarck, et al., 1994). The volcanic activity was coeval with the Nazas arc activity and The continental redbeds assigned to the upper part of La Boca Formation were deposited probably during a period of crustal extension that followed the Early Jurassic magmatic arc activity (Fastovsky et al., 2005; Barboza-Gudiño et al., 2008), or in a back-arc setting related to the Nazas arc. As previously mentioned, the interlayered volcanic rocks yielded an age of 189.0 ± 0.2 Ma (U-Pb, zircon) in the Huizachal Valley (Fastovsky et al, 2005) and a 193 ± 0.2 Ma U-Pb zircon age (Barboza-Gudiño et al., 2008) for an ignimbrite of the Aramberri area. Volcanic arc provenances and notable content of early to middle Jurassic aged zircons, are characteristic of these units. The results of detrital zircon geochronology (Figure 5) are also in agreement with an Early Jurassic age of deposition for the succession, and provenances from Grenvillian-panafrican basement and permotriassic rocks. The La Boca Formation overlies unconformable the Triassic El Alamar Formation in La Boca canyon, a Permian turbiditic succession in the Peregrina Canyon of the Huizachal Peregrina Anticlinorium, Early Jurassic volcanic rocks in Aramberri and is in turn unconformably overlain by the callovian-oxfordian La Joya Formation.

3.5 Erosional unconformity and Middle Jurassic alluvial to lagunar deposits (La Joya Formation)

La Joya Formation was defined by Mixon et al. (1959) as Middle to Late Jurassic conglomeratic and redbeds sequence exposed in the Huizachal-Peregrina anticlinorium. They proposed the Rancho La Joya Verde in the Huizachal valley as type locality.

La Joya Formation in the Huizachal-Peregrina anticlinorium, consist of a fining upward megasequence composed of a basal polymictic breccia or conglomerate-fanglomerate facies followed by red sandstones, siltstones and mudstones. The clastic components are volcanic or plutonic, metamorphic and sedimentary rocks as well as abundant white quartz and brown-gray chert. The sandstones and siltstones are brown-red, occasionally with gray, purple and green layers. To the top changes gradually into lagoon or shallow marine deposits, containing interlayered evaporites, regularly gypsum and fine laminated limestone. The La Joya Formation changes typically in their thickness, varying from 0 to more than 200 m in the different localities from central to northeastern Mexico. La Joya Formation represents the basal strata of the marine Upper Jurassic-Cretaceous succession.

The interpretation of the different facies of La Joya Formation include several depositional environments as interpreted from Michalzik (1988), as follows: alluvial fan fanglomerates, channels and distal alluvial fan conglomerates, shallow marine carbonates and caliche crusts, finer grained alluvial plain deposits and lagoon to sabckha evaporites.

The age was established in accordance to their stratigraphic position, overlying Early Jurassic redbeds and volcanic rocks, and underlying Kallovian-Oxfordian gypsum and limestone. Detrital zircon geochronology results are also in agreement with a Middle to early Late Jurassic age for this unit, yielded maximal depositional ages between 175 and 178 Ma (Rubio-Cisneros and Lawton, 2011) and (Barboza-Gudiño and Zavala-Monsivais, 2011), considering that two of the results presented by Rubio-Cisneros and Lawton (2010) for La Boca Formation, correspond in the interpretation by this study, to La Joya Formation, following definition from Mixon et al. (1959).

4. Conclusions

Figure 7 shows the stratigraphic correlation of the Early Mesozoic units outcropping in central to Northeastern Mexico. Upper Triassic turbidities that appear in the Mesa central province and are known as Zacatecas Formation, correspond to a subsea fan known as the Potosí fan (Centeno-García, 2005). The Potosí fan was formed in a geoclinal setting at the western equatorial margin of Pangaea. Meanwhile in the Sierra Madre Oriental, an in age comparable fluvial succession, defined as El Alamar Formation (Barboza-Gudiño, et al., 2010), represents remnants of a river system known as El Alamar River, that was housed in a rift associated to the break up of Pangea. According to provenance and distribution of both, continental and marine Triassic deposits, it can be interpreted that El Alamar River fed the sedimentation in to the Potosí subsea fan.

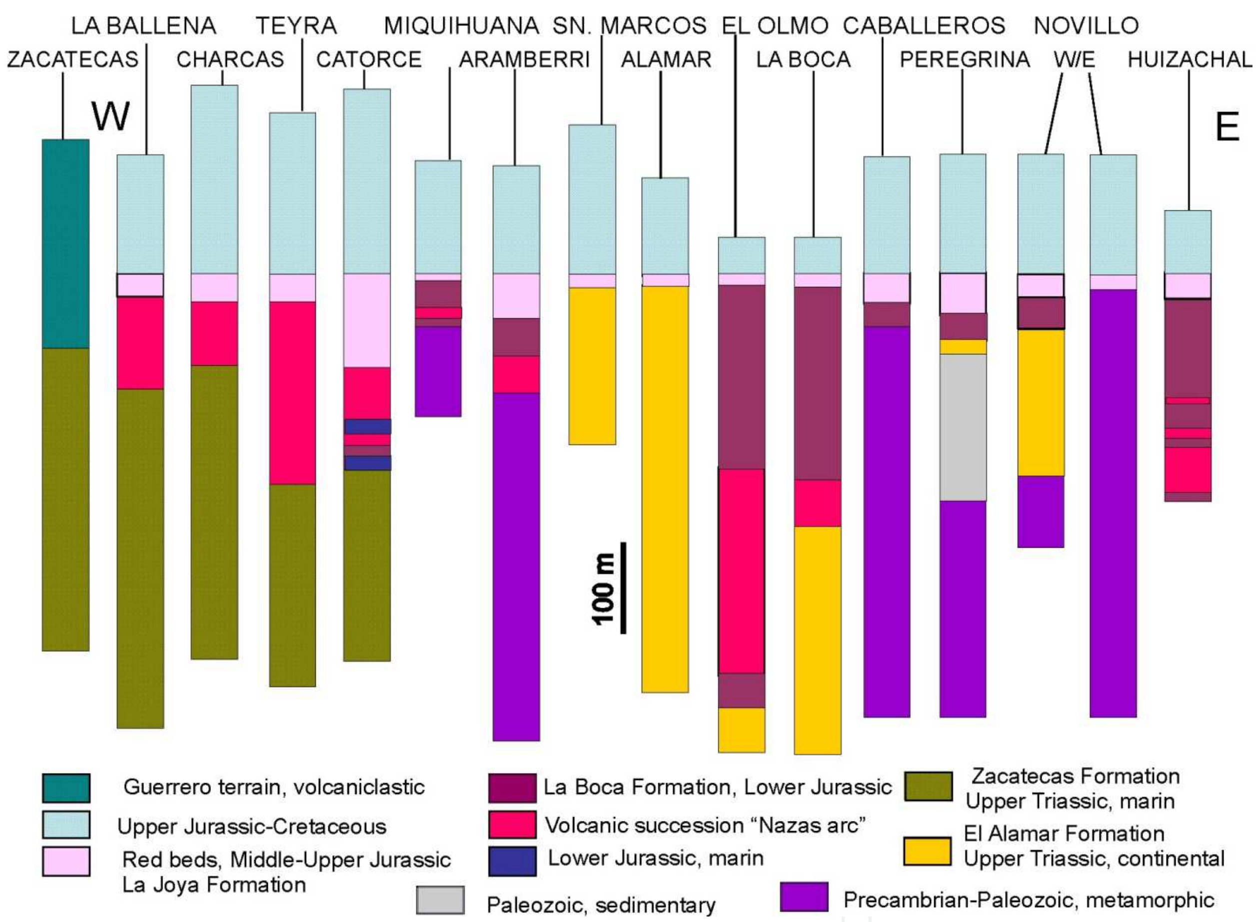


Fig. 7. Stratigraphic correlation of Early Mesozoic units from central to northeastern Mexico, for location see figure 1

During the earliest Jurassic time, continued in these region similar conditions as in the upper Triassic, where river systems drained continental blocks that had been part of Pangaea that now begining to disperse. At this time, fluvial and alluvial red beds of La Boca Formation (Mixon et al., 1959), known also as Huizachal Formation (Imlay, 1948, Carrillo-Bravo, 1961), were deposited to the mainland and towards the Pacific were deposited the marine facies of the Huayacocotla Formation, both units, contemporary and in some places interstratified with the early Jurassic volcanic arc or Nazas Formation (Pantoja-Alor, 1972).

Finally La Joya Formation (Mixon et al., 1959), initially considered part of the Huizachal Group, besides La Boca Formation, represents an erosional unconformity linked to the opening of the Golf of Mexico basin as a brake up unconformity and in this sense the basal unit of the Middle to Late Jurassic marine succession, related to a transgression coming from the east. During the Late Jurassic-earliest Cretaceous, the pacific connection from the central Mexico basin was closed through the presence of the composed Guerrero superterrane, an intraoceanic arc complex linked to subduction processes evolved to the west of the ancient early Mesozoic subduction zone. At this time, the only connection from eastern Mexico to an oceanic basin was to the Atlantic, through the new opened Gulf of Mexico.

5. References

Bacon, R. W. (1978). Geology of the northern Sierra de Catorce, San Luis Potosí, México (master thesis): *Arlington, University of Texas,* 124 p.

Barboza-Gudiño, J.R., Hoppe, M., Gómez-Anguiano M., and Martínez-Macías, P.R. (2004). Aportaciones para la interpretación estratigráfica y estructural de la porción noroccidental de la Sierra de Catorce, San Luis Potosí, México: *Revista Mexicana de Ciencias Geológicas,* Vol. 21, pp. 299-319.

Barboza-Gudiño J. R., Orozco-Esquivel M. T., Gómez-Anguiano M., and Zavala-Monsiváis A. (2008). The Early Mesozoic volcanic arc of western North America in northeastern Mexico: *Journal of South American Earth Sciences*: Vol. 25, pp. 49-63.

Barboza-Gudiño, J. R., Ramirez-Fernández, J. A., Torres-Sanchez, S. A., Valencia, V. A. (2011). Geocronología de circones detríticos de diferentes localidades del esquisto Granjeno en el Noreste de México; *Boletín de la Sociedad Geológica Mexicana*, Vol. 63 No. 2, pp. 201-216.

Barboza-Gudiño, J. R., Tristan-Gónzalez, M., and Torres-Hernández, J. R. (1999). Tectonic setting of pre-Oxfordian units from central and northeastern-Mexico: A Review, *in* Bartolini, C., Wilson, J. L., and Lawton, T. F., eds., Mesozoic Sedimentary and Tectonic History of North-Central Mexico: *Geological Society of America Special Paper* 340, pp.197-210.

Barboza-Gudiño, J.R., Torres-Hernández, J.R., and Tristán-González, M. (1998). The Late Triassic-Early Jurassic active continental margin of western North America in northeastern México: *Geofísica Internacional*, Vol. 37, pp. 283-292.

Barboza-Gudiño, J. R., Zavala-Monsivais, A., Venegas-Rodriguez, G., Barajas-Nigoche, L. D. (2010). Late Triassic stratigraphy and facies from northeastern Mexico: Tectonic setting and provenance, *Geosphere,* October 2010 Vol. 6; No. 5, pp. 621-640.

Bartolini, C. (1998). Stratigraphy, geochemistry, geochronology and tectonic setting of the Mesozoic Nazas Formation, north-central Mexico (Ph.D. thesis): *University of Texas at El Paso*, 557 p.

Bartolini, C., Spell, T. (1997). An Early Jurassic age (40Ar/39Ar) for the Nazas Formation at the Canñada Villa Juárez, northeastern Durango, México. *Geological Society of America, Abstracts with Programs*, Vol. 29, No. 2, p. 3.

Bartolini, C., Lang, H., Cantú-Chapa, A., and Barboza-Gudiño, J. R. (2001). The Triassic Zacatecas Formation in central Mexico : Paleotectonic, paleogeographic and paleobiogeographic implications, *in* Bartolini, C., Buffler, R.T., and Cantú-Chapa, A., eds., The western Gulf of Mexico Basin: Tectonics, sedimentary basins and petroleum systems: *American Association of Petroleum Geologists Memoir* 75, pp. 295-315.

Bartolini, C., Lang, H., Spell, T. (2003). Geochronology, geochemistry, and tectonic setting of the Mesozoic Nazas arc in north-central Mexico, and its continuation to north South America. In: Bartolini, C., Buffler, R.T., Blickwede, J.F. (Eds.), The Circum Golf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation and plate tectonics. *American Association of Petroleum Geologists Memoir,* 79, pp. 427-461.

Blickwede, J.F. (2001). The Nazas Formation: A detailed look at the early Mesozoic convergent margin along the western rim of the Gulf of Mexico Basin. In: Bartolini C., Buffler R.T., Cantu´-Chapa, A. (Eds.), The Western Gulf of Mexico Basin: Tectonics, Sedimentary Basins, and Petroleum Systems. *American Association of Petroleum Geologists Memoir,* 75, pp. 317–342.

Burckhardt, C., and Scalia, S. (1905). La faune marine du Trias Supérieur de Zacatecas: Instituto de Geología de México Boletín 21, 44 p.

Cantú-Chapa, A. (1969). Una nueva localidad del Triásico Superior marino en México: *Instituto Mexicano del Petróleo, Revista*, Vol. 1, pp. 71-72.

Carrillo-Bravo J. (1961). Geología del Anticlinorio Huizachal-Peregrina al NW de Ciudad Victoria, Tamaulipas: *Boletín de la Asociación Mexicana de Geólogos Petroleros,* Vol. 13, pp. 1-98.

Carrillo-Bravo. J. (1982). Exploración petrolera de la Cuenca Mesozoica del Centro de México: *Boletín de la Asociación Mexicana de Geólogos Petroleros*, Vol. 34, pp. 21-46.

Centeno-García, E. (2005). Review of Upper Paleozoic and Mesozoic stratigraphy and depositional environments of central and west Mexico: Constraints on terrane analysis and paleogeography, *in* Anderson T. H., Nourse, J. A., McKee, J. W., and Steiner, M. B., *eds*., The Mojave-Sonora Megashear hypothesis: Development, assessment and alternatives: *Geological Society of America Special Paper* 393, pp. 233-258.

Centeno-García, E. and Silva-Romo, G. (1997). Petrogenesis and tectonic evolution of central Mexico during Triassic-Jurassic time: *Revista Mexicana de Ciencias Geológicas*, Vol.14, No. 2, pp. 244-260.

Clarck, J. M., Montellano, M., Hopson, J. A., Hernández, R. R., and Fastovsky, D. E. (1994). An Early or Middle Jurassic tetrapod assemblage, from the La Boca Formation, northeastern Mexico, in Fraser, N. C., and Sues, H.-D., eds. In the Shadow of the Dinosaurs: Cambridge, *Cambridge University Press,* pp. 294-302.

Chávez-Aguirre, R. (1968). Bósquejo Geológico de la Sierra Peñón Blanco, Zacatecas, Tesis Profesional: *Facultad de Ingeniería, Universidad Nacional Autónoma de México,* 67 p.

Córdoba-Méndez, D. A. (1964). Geology of Apizolaya quadrangle (east half), northern Zacatecas, Mexico (master thesis*): The University of Texas at Austin,* 111 p.

Cuevas Pérez, E. (1985). Geologie des Alteren Mesozoikums in Zacatecas und San Luis Potosí, Mexiko (Ph.D. thesis): *Hessen Marbur/Lahn, Germany*, 182 p.

Davila-Alcocer, V. M., Centeno-García, E., Barboza-Gudiño, J.R., Valencia, V. A., Fitz-Diaz, E. (2008). Detrital zircón ages from the El Chilar accretionary complex and volcaniclastic rocks of the San Juan de La Rosa Formation, Tolimán, Queretaro, Mexico. *Geological Society of America, Abstracts with Programs*, 167-3.

de Cserna, Z. (1956). Tectónica de la Sierra Madre Oriental de México, entre Torreón y Monterrey. *XX. Congreso Geológico Internacional,* México, 87 p.

Dickinson, W. R. (1985). Interpreting provenance relations from detrital modes of sandstones, *in* Zuffa, G. G., ed. Provenance of arenites: *Reidel Publishing, Lancaster*, pp. 333-361.

Dickinson, W. R., Beard, L. S., Brakenridge, G. R., Erjavec, J. L., Ferguson, R. C., Inman, K. F., Knepp, R. A., Lindberg, F. A., and Ryberg, P. T. (1983). Provenance of North

American Phanerozoic sandstones in relation to tectonic setting, *Geological Society of America Bulletin* Vol. 94, p. 222-235.

Dickinson, W.R., and Lawton, T.F. (2001). Carboniferous to Cretaceous assembly and fragmentation of Mexico: *Geological Society of America Bulletin,* Vol. 113, pp.1142-1160.

Fastovsky, D. E., Hermes, O. D., Strater, N. H., Bowring, S. A., Clarck, J. M., Montellano, M., Hernández, R. R. (2005). Pre-Late Jurassic, fossil-bearing volcanic and sedimentary red beds of Huizachal Canyon, Tamaulipas, Mexico, *in* Anderson T. H., Nourse, J. A., McKee, J. W., and Steiner, M. B., *eds*., The Mojave-Sonora Megashear hypothesis: Development, assessment and alternatives: *Geological Society of America Special Paper* 393, pp.233-258.

Franco-Rubio, M. (1999). Geology of the basement below the decollement surface, Sierra de Catorce, San Luis Potosí, México. in Bartolini, C., Wilson, J. L. and Lawton, T. F. (eds.), Mesozoic Sedimentary and Tectonic History of North-Central Mexico: *Geological Society of America Special Paper* 340, pp.211-227.

Fries, C., and Rincón-Orta, C. (1965). Nuevas aportaciones geocronológicas y técnicas empleadas en el laboratorio de geocronometría; *Boletín del Instituto de Geología, Universidad Nacional Autónoma de México*, Vol. 73, pp. 57-133.

Gallo-Padilla, I., Gómez-Luna., M. E., Contreras, B., and Cedillo, P. E. (1993). Hallazgos Paleontológicos del Triásico marino en la región central de México: *Revista de la Sociedad Mexicana de Paleontología*, Vol. 6, pp.1-9.

Garzanti, E., Doglioni, C., Vezzoli, G., Andò, S. (2007). Orogenic belts and orogenic sediment provenance. *The Journal of Geology*, Vol. 115, pp. 315-334.

Gehrels, G. E., Valencia, V.A, and Pullen A. (2006). Detrital zircon geochronology by Laser Ablation Multicollector ICPMS at the Arizona LaserChron Center, in Olszewski, T., ed., Geochronology: Emerging opportunities, Paleontology Society Short Course: Philadelphia, PA, *Paleontological Society Papers,* Vol. 12, pp. 67-76.

Gómez-Luna, M. E., Cedillo-Pardo. E., Contreras, B., Gallo-Padilla, I., and Martínez-Cortés, C. A. (1998). El Triásico marino de la Mesa Central de México: Implicaciones Paleogeográficas: *II convención sobre la evolución geológica de México y de recursos asociados, Simposia y Coloquio, extended abstracts*, pp. 67-71.

Grajales-Nishimura, J.M., Terrell, D., Damon, P. (1992). Evidencias de la prolongación del arco volcánico cordillerano del Triásico tardío-Jurásico en Chihuahua, Durango y Coahuila. *Boletín de la Asociación Mexicana de Geólogos Petroleros*, Vol. 42, pp. 1–18.

Gutierrez-Amador, M. (1908). Las capas cárnicas de Zacatecas: *Boletín de la Sociedad Geológica Mexicana*, Vol. 4, pp. 29-35.

Hoppe, M., Barboza-Gudiño, J. R., and Schulz, H. M. (2002). Late Triassic submarine fan in northwestern San Luis Potosí, México –lithology, facies and diagenesis, *Neues Jahrbuch Geologie und Paläontologie*, Vol. 2002, No.12, pp.705-724.

Imlay, R. W., Cepeda, E., Álvarez, M., Jr., and Diaz, T. (1948). Stratigraphic relations of certain Jurassic formations in eastern Mexico: *American Association of Petroleum Geologists, Bulletin,* Vol. 32, pp.1750-1761.

Jones, N.W., J.W. McKee, T.H. Anderson, and L.T. Silver. (1995). Jurasic Volcanic rocks in northeastern Mexico: A possible remnant of a Cordilleran magmatic arc. In C. Jacques-Ayala, C. González-León, and J. Roldán-Quintana, eds., Studies on the Mesozoic of Sonora and adjacent areas: *Geological Society of America Special Paper* 301, pp. 179-190.

López-Infanzón, M. (1986). Estudio petrogenético de las rocas ígneas en las Formaciones Huizachal y Nazas: *Boletín de la Sociedad Geológica Mexicana,* Vol. 47, No. 2, pp.1-42.

Ludwig, K.R. (2003). Isoplot 3.00: *Berkeley Geochronology Center Special Publication* Vol. 4, 70 p.

Marsaglia, K. M., e Ingersoll, R. V. (1992). Compositional trends in arc-related deep-marine sand and sandstone: A reassessment of magmatic-arc provenance, *Geological Society of America Bulletin*, Vol. 104, pp. 1637-1649.

Maldonado-Koerdell, M. (1948). Nuevos datos geológicos y paleontológicos sobre el Triásico de Zacatecas: *Anales de la Escuela Nacional de Ciencias Biológicas*, Vol. 5, pp. 291-306.

Martínez-Pérez, J. (1972). Exploración geológica del área El Estribo-San Francisco, San Luis Potosí: *Boletín de la Asociación Mexicana de Geólogos Petroleros,* Vol. 24, No. 7-9, pp. 327-402.

McLennan, S. M., Hemming, S., McDaniel, D. K., and Hanson, G. N. (1993). Geochemical approaches to sedimentation, provenance, and tectonics, *in* Johnsson, M. J., and Basu, A., *eds*., Processes Controlling the Composition of Clastic Sediments: *Geological Society of America Special Paper* 284., pp. 21-40.

Miall, A. D. (1977). A review of the braided-river depositional environment: *Earth Sciences Review*, Vol. 13., pp.1-62.

Michalzik, D. (1991). Facies sequence of Triassic-Jurassic red beds in the Sierra Madre Oriental (NE Mexico)and its relation to the early opening of the Gulf of Mexico. *Sedimentary Geology*, Vol. 71, pp. 243-259.

Miller, B. V., Dostal, J., Keppie, J. D., Nance R. D., Ortega-Rivera, and Lee, J. K. W. (2007). Ordovician calc-alkaline granitoids in the Acatlán Komplex, southern Mexico: Geochemical and geochronologic data and implications for the tectonics of the Gondwanan margin of the Rheic Ocean, *in* Linneman, U., Nance, R. D., Kraft, P., and Zulauf, G., *eds*. The evolution of the Rheic Ocean: From Avalonian-Cadomian active margin to Alleghenian-Variscan collition: *Geological Society of America, Special Paper* 423, pp. 465-475.

Mixon, R. B., Murray, G. E., and Diaz, T. G. (1959). Age and correlation of Huizachal Group (Mesozoic), state of Tamaulipas, Mexico: American Association of Petroleum Geologists Bulletin, v. 43, p.757-771.

Mutti, E., and Ricci-Lucchy, F., 1972, Le torbiditi dell 'apennino settentrionale; introfuzione all 'analisi di facies. Memoir Society Geology Italy 11, 161-199 (1978, English translation in International Geology Review, v. 20, p.125-166).

Nance, R.D., Fernández-Suárez, J., Keppie, J.D., Storey, C., Jeffries, T.E., 2007, Provenance of the Granjeno Schist, Ciudad Victoria, Mexico: Detrital zircon U-Pb age constraints and implication for the Paleozoic paleogeography of the Rheic Ocean, *en* Linnemann, U., Nance, R.D., Kraft, P., Zulauf, G. (eds.), The evolution of the Rheic Ocean: From Avalonian-Cadomian active margin to Alleghenian-Variscan collision: Geological Society of America Special Paper 423, 453-464.

Ortega-Gutiérrez, F., Ruiz, J, and Centeno-García, E. (1995). Oaxaquia, a Proterozoic microcontinent accreted to North America during the Late Paleozoic: Geology, v. 23, p.1127-1130.

Pantoja-Alor, J. (1972). La Formación Nazas del Levantamiento de Villa Juárez, Estado de Durango. Memorias de la Segunda Convención Nacional de la Sociedad Geológica Mexicana, p. 25-31.

Rueda-Gaxiola, J., Dueñas, M. A., Rodríguez, J. L., Minero M., and Uribe, G. (1993). Los Anticlinorios de Huizachal-Peregrina y de Huayacocotla: Dos partes de la fosa de Huayacocotla-El Alamar: *Boletín de la Asociación Mexicana de Geólogos Petroleros,* Vol. 43, pp. 1-29.

Rueda Gaxiola, J., López-Ocampo, E., Dueñas, M. A., Rodríguez, J. L., and Torres-Rivero, A. (1999). Palynostratigraphical method: Basis for defining stratigraphy and age of the Los San Pedros allogroup, Huizachal-Peregrina Anticlinorium, Mexico, *in* Bartolini, C., Wilson, J. L., and Lawton, T. F., eds., Mesozoic Sedimentary and tectonic history of north-central Mexico: *Geological Society of America Special Paper* 340, pp. 229-269.

Reynoso-Rosales, V. H. (1992). Descripción de los esfenodontes (Sphenodontia, Reptilia) de la fauna del cañón del Huizachal (Jurásico temprano a medio) Tamaulipas, México (MS. Tesis) Universidad Nacional Autónoma de México, Facultad de Ciencias, 86 p.

Reynoso-Rosales, V. H. (1996). A Middle Jurassic Sphenodon-like sphenodontian (Diapsida: Lepidosauria) from Huizachal Canyon, Tamaulipas; Journal of Vertebrate Paleontology, v. 16, p. 210-221.

Rubio-Cisneros, I. I., Timothy, F. Lawton. (2011). Detrital zircon U-Pb ages of sandstones in continental red beds at Valle de Huizachal, Tamaulipas, NE Mexico: Record of Early-Middle Jurassic arc volcanism and transition to crustal extension; *Geosphere,* Vol. 7, pp. 159-170.

Silva-Romo, G., Arellano-Gil, J., Mendoza-Rosales, C., and Nieto-Obregón, J. (2000). A submarine fan in the Mesa Central, Mexico: Journal of South American Earth Sciences, v.13. p.429-442.

Tristán-González, M., Torrez-Hernández, J. R., Mata-Segura, J. L. (1995) Geología de la Hoja Presa de Santa Gertrudis, S. L. P., Instituto de Geología, Universidad Autónoma de San Luis Potosí, Folleto Técnico no. 122, 50 p.

Torres, R., Ruiz, J., Patchett, P.J., Grajales, J.M. (1999). Permo-Triassic continental arc in eastern México: Tectonic implications, for reconstructions of southern North America. In: Bartolini, C., Wilson, J.L., Lawton, T.F. (Eds.), Mesozoic Sedimentary and Tectonic History of North-Central Mexico. *Geological Society of America Special Paper*, 340, pp. 191-196.

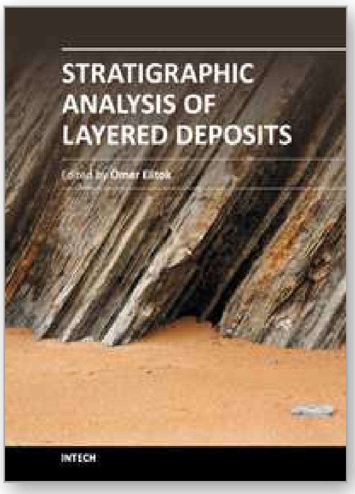
Vega-Granillo, R., Salgado-Souto, S., Herrera-Urbina, S., Valencia, V., Ruiz, J., Mesa-Figueroa, D., and Talavera-Mendoza, O., (2008) U-Pb detrital zircon data of the Rio Fuerte Formation (NW Mexico): Its peri-Gondwanan provenance and exotic nature in relation to southwestern North America*: Journal of South American Earth Sciences,* Vol. 26, pp. 343–354.

Venegas-Rodriguez, G., Barboza-Gudiño, J. R., López-Doncel, R. A. (2009). Geocronología de circones detríticos en capas del Jurásico Inferior de las áreas de la Sierra de Catorce y El Alamito en el estado de San Luis Potosí: Revista Mexicana de Ciencias Geológicas 26 (2), p. 466-481.

Weber, R., (1997). How old is the Triassic Flora of Sonora and Tamaulipas and news on Leonardian floras in Puebla and Hidalgo, México: Revista Mexicana de Ciencias Geológicas, Vol. 14 No. 2, 225-243.

Zavala-Monsiváis, A., Barboza-Gudiño, J. R., Valencia, V. A., Rodríguez-Hernández, S. E., García Arreola, M. E. (2009). Las sucesiónes volcánicas pre-Cretácicas en el noreste de Méxcio; Unión Geofísica Mexicana, GEOS, 29 (1), resúmenes de la reunión anual nov. 2009, Puerto Vallarta Jalisco., p. 53.

Zavala-Monsiváis, A., Barboza-Gudiño, J. R., Velasco-Tapia, F., García-Arreola, M. E. (in Press). Edad y correlación de la sucesión volcánica Jurásica expuesta al poniente de Charcas, San Luis Potosí; *Boletín de la Sociedad Geológica Mexicana.*



Stratigraphic Analysis of Layered Deposits
Edited by Dr. Ömer Elitok

ISBN 978-953-51-0578-7
Hard cover, 298 pages
Publisher InTech
Published online 27, April, 2012
Published in print edition April, 2012

Stratigraphy, a branch of geology, is the science of describing the vertical and lateral relationships of different rock formations formed through time to understand the earth history. These relationships may be based on lithologic properties (named lithostratigraphy), fossil content (labeled biostratigraphy), magnetic properties (called magnetostratigraphy), chemical features (named chemostratigraphy), reflection seismology (named seismic stratigraphy), age relations (called chronostratigraphy). Also, it refers to archaeological deposits called archaeological stratigraphy. Stratigraphy is built on the concept "the present is the key to the past" which was first outlined by James Hutton in the late 1700s and developed by Charles Lyell in the early 1800s. This book focuses particularly on application of geophysical methods in stratigraphic investigations and stratigraphic analysis of layered basin deposits from different geologic settings and present continental areas extending from Mexico region (north America) through Alpine belt including Italy, Greece, Iraq to Russia (northern Asia).

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821