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Geological and geochemical evidence for a Mesozoic marginal basin in western Mexico: Implications for regional ore genesis in the Guerrero province

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ABSTRACT

Field mapping of widely distributed Jurassic marine strata and submarine volcanic rocks in western Mexico support reinterpretation of the Guerrero terrane as a continental margin basin province initiated by Triassic rifting rather than an accreted arc terrane. Regional mapping indicates that the Cananea Trend, a well-known alignment of porphyry copper districts in northern Mexico, reflects a major fault separating the North American craton from the extended cratonic crust floor of this marginal rift basin. Early to Middle Jurassic silicic volcanic rocks and clastic sediments fill the northern portion of the marginal basin and grade upsection to dominantly marine shale, mudstone, turbidites and submarine volcanic rocks (Late Jurassic where dated) to the south. The volcanic rocks throughout the Jurassic, Cretaceous and into the Middle Tertiary are believed to represent a continental to continental margin arc, initiated as early as the Late Triassic, which cut the continental margin basin. The Jurassic sediments extend from north central Sonora at least as far south as the southwestern part of the state of Durango. In exposures at Moris, Chihuahua, multi-kilometer scale blocks of Proterozoic gneiss and granite, and Paleozoic quartzite and limestone, are surrounded and partially covered by the Jurassic strata, a relationship that is consistent with extended crust.

Tourmaline occurrences and molybdenum (Mo) systems crop out principally in Laramide stocks, batholiths and coeval volcanic phases in a belt from southwestern Arizona to at least as far south as Mazatlan, Sinaloa. Both the tourmaline and Mo principally occur where the Laramide batholiths cut the proposed continental margin basin. The abundance of tourmaline in these systems suggests assimilation or hydrothermal extraction by the magmas of boron from boron-enriched shale from the basin and by inference the Mo as well. Porphyry copper deposits along the Cananea rift margin contain more tourmaline and Mo (greater than 0.015% Mo) than is typically found elsewhere in the southwestern North America porphyry province to the east. Porphyry mineral systems within the proposed marginal basin shale-turbidite-volcanic province are more typically Mo deposits rather than Cu deposits. The typically younger Au deposits within the proposed basin limits represent a major part of Mexico's total Au resource. The coincidence of tourmaline and many of the Mo systems in the region with the Jurassic marine sediment belt suggests a genetic tie. While the correlation is not nearly as strong for gold, it may also reflect a genetic tie.

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INTRODUCTION

The principal proposed model for the distribution of metals in Mexico by Clark and others (1982) ties metal distribution to the inward and return sweep of continental magmatism resulting from the varying dip of the subducting Pacific oceanic plate under Mexico since the Jurassic. They proposed that the distribution of the various mineral belts, parallel to the subducting margin, clearly ties the mineral belts to the evolution of the subducting plate rather than crustal variation. Alternatively, Valencia-Moreno and others (2006) proposed that variations of porphyry-copper style mineralization in the region reflect the general patterns of basement distribution along Mexico's west coast.

Campa and Coney (1983) first introduced the concept of the Guerrero suspect accreted terrane in their tectonic model of Mexico. This model has acquired general acceptance with a variety of modifications by subsequent authors. Sedlock and others (1993) divided and renamed the Guerrero terrane with a complex accretionary and translational construction of most of the Mexican craton. Dickinson and Lawton (2001) proposed recombining the Guerrero and added Baja California as part of an accreted oceanic arc of their Guerrero superterrane. Wetmore and Paterson (2003) divided the superterrane into three terranes; the Santiago Peak and Guerrero with continental sediment-wedge basement and the Alistos with an oceanic crustal floor. Centeno-García (2005) preferred keeping the Guerrero as a composite terrane because of evidence of continuity within the terrane during the Cretaceous.

As the Guerrero accretion model has evolved, other authors have accumulated evidence which appears inconsistent with an accretionary arc model. Malpica (1972) recognized Carboniferous fossils in the San Jose de Gracia area on the Sinaloa-Chihuahua border. This Paleozoic zone extends to the west into the El Fuerte region (Mullan, 1978) east of the Triassic Francisco Gneiss. This block of Paleozoic forms the Rusias Terrane of Campa and Coney (1983). Henry and Fredrikson (1987) recognized Paleozoic sediments near Mazatlan. Gastil and others (1991) confirmed Malpica's observations of Paleozoic sediments. Centeno-García and others (1993) determined that the provenance of the Arteaga Triassic gneiss of western Michoacan in southwestern Mexico included Paleozoic and Precambrian zircons. Lang and others (1996) found no stratigraphic or structural discontinuities that required accreted terrane boundaries in southern Mexico. Lyons (2002) proposed the Cananea-Indé fault as a Triassic rift margin of west Mexico separating Late Paleozoic North America from a Jurassic marginal rift basin. Lawton and others (2003) mapped outcrops of Jurassic basin sediments in the Cucurpe area of central Sonora. Because of the lack of a comprehensive study of the Jurassic in western Mexico, Lawton and others (2003), Anderson and Nourse (2005) and Haenggi and Muehlberger (2005) proposed the Cucurpe Basin as one of a system of pull-apart basins in which the Jurassic marine sediments accumulated. Keppie and others (2006) interpreted the Francisco Gneiss on the Sonora-Sinaloa border as having formed in a Triassic rift environment.

The purpose of this paper is to present evidence for the development of a Jurassic marginal rift basin in western Mexico, document the distribution of certain types of metal enrichments in this region, and to suggest a model that relates the origin of the mineralization with the proposed marginal basin. This study has been part of a career-long study of Mexican geology and its ore deposits, volcanic rocks, and regional basement and tectonic history. It is one of a planned series of articles documenting these observations and the resulting interpretations.

JURASSIC MARINE OUTCROPS OF WESTERN MEXICO

The intention of this discussion is to define the Guerrero Rift Basin spatially, reserving the detailed observations, which define the basin as a marginal rift basin, for other venues. The dominant assemblage of these proposed Jurassic rocks are black, carbon-rich, deep-water marine shale typically with thin distal sandy turbidites. Outcrops of this lithology extend from north central Sonora to southwest Chihuahua. Studies in progress by Lawton and others (2003) and Peryam and others (2005) have advanced current knowledge of Late Jurassic sediments in the Cucurpe area of north-central Sonora with mapping and U-Pb provenance studies. Villasenor and others (2005) interpret ammonite and belemnite fossils found at Cucurpe as Late Jurassic in age. This study is expanding the provenance studies to Batopilas and Moris, Chihuahua and Arizpe, Sonora and fossil studies to Batopilas.

A plot of the distribution of known marine Jurassic and Cretaceous deep-water sediments in western Mexico (Fig. 1) illustrates the basis for the proposed Jurassic marginal rift basin. Most structural boundaries to the basin result from the projection of many isolated mapped segments that reveal the major stratigraphic changes across them. The most important of these is the Cananea rift-margin fault (Fig. 1), which separates the basin from the North American craton.

Within the deep-marine shale, the principal lithologic variation observed in this study consists of thin-bedded mudstone, shale, and sandstone believed to be more representative of the slope environment. This lithology crops out at Parral, Chihuahua; Chirimoyo, Durango; and Sara Alicia, Sonora. The only known age determination on this group of sedimentary rocks is Late Jurassic to Early Cretaceous at Parral carried out by PEMEX (Eguiluz de Antuñano and Campa, 1982).

In north central Sonora, Early to Middle Jurassic volcanic rocks with some interbedded arenite dominate the Jurassic section. Limited localities of Late Jurassic marine shale occur southwest of Nogales, Sonora. To the south the Late Jurassic sediments begin to dominate the exposed Jurassic section. Moris and Batopilas, Chihuahua, contain similarly altered andesitic rocks emplaced in the dominant marine sedimentary section.

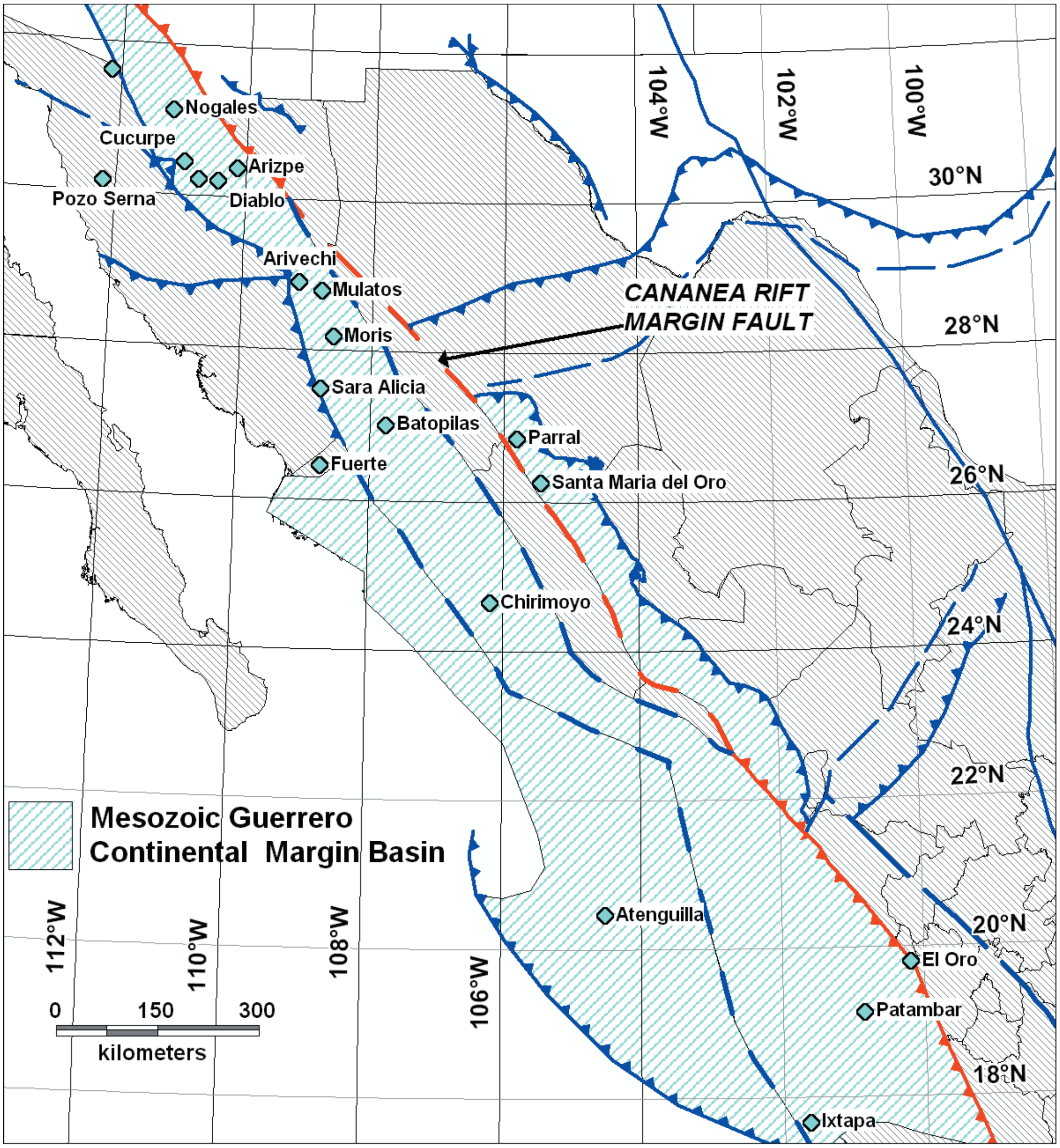

Figure 1. Outcrops of the Guerrero Basin sediments (blue diamonds) most of which have been visited as part of this study. Ixtapa and Atengilla are probably Late Cretaceous in age, while Parral sediments have been dated by PEMEX as Late Jurassic and Early Cretaceous. Nearly identical lithologies of turbiditic sand and mud observed at Parral, Sara Alicia and Chirimoyo suggest at least a similar slope depositional environment and possibly a similar age. Outcrops from Batopilas up through northern Sonora contain similar deep-marine black shale, dated at Cucurpe and at Batopilas as Late Jurassic. The blue shaded area is the proposed area of the Mesozoic Guerrero marginal rift basin and the Parral-Proaño thrust belt of these same sediments.

Newly mapped or reinterpreted outcrop areas, which reveal geologic relationships important to understanding the Jurassic history of the region, include Batopilas, Chihuahua and Moris, Chihuahua. Additional outcrops such as Arivechi, Chirimoyo, Rio Mulatos, Sara Alicia and others still need more study.

Batopilas, Chihuahua

The Batopilas geologic quadrangle map (INEGI, 1995) does not indicate any Jurassic sedimentary or volcanic rocks in the Batopilas Silver District, nor does the district study of Wilkerson and others (1988). New mapping by the author confirms unpublished company reports of sedimentary rocks and identifies these rocks and associated volcanic rocks as the major host rock to the silver veins in the district. The sediments consist of deep-marine sediments, turbiditic sandstones and interfingering andesitic volcanic rocks. Preliminary fossil identification (T. Lawton, personal communication) suggests that the ammonites, belemnites, gastropods and pelecypods encountered correlate with those identified in the Jurassic Cucurpe Formation (Villasenor and others, 2005) 500 km to the northwest of Batopilas. The marine sediments interfinger with the highly altered andesite flows and flow breccias of two stacked submarine volcanic sequences. Wilkerson and others (1988) referred to these igneous rocks as the Pastrana Dacite but lumped all of the sediments with the igneous rocks. Strong albitization (Na) of the plagioclase in the submarine environment appears to have obscured protolith identification, but Wilkerson's own chemical data (1983) indicate andesitic composition. A provenance study of turbiditic sandstones from the marine shale indicates a late Jurassic age for the turbidite-marine shale sequence.

Moris, Chihuahua

Jurassic shale is located east of Pilar de Moris and north of the village of Moris (INEGI, 1989). Proterozoic gneiss is also indicated to the north of Moris and possible Proterozoic limestone and sandstone are plotted to the east of Moris. Remapping in this study indicates a very different distribution of rocks, with two blocks of Proterozoic gneiss capped with a basal Paleozoic quartzite and overlying Paleozoic limestone. These two basement blocks protrude up to 500 meters into the black shale interbedded with distal turbidite sandstones, exhibit differing structural orientations, and are separated from each other by these sediments at the base of the 500 meters of exposed relief. The shale also contains andesite dikes, sills and igneous breccia pipes with very similar lithologies to those found at Batopilas. A clear syndepositional relationship occurs at Batopilas but has not been proven at Moris. The gold mine 5 km north of Moris, Chihuahua, located on the Hoja topographic quadrangle map (INEGI, 1993), occurs in mineralized Jurassic and Paleozoic sediments where they are cut by an altered felsic porphyry.

Sonoran occurrences

Thirty kilometers southwest of Nogales, black shale crops out spatially associated with known Jurassic rhyolitic volcanic rocks. Fifteen kilometers west of Arispe, Sonora, apparent Jurassic black shale crops out between Curcurpe and Arizpe. Southeast of Arivechi, Sonora, a slice of Jurassic shale with ammonites is affected by Cenomanian thrust faults (Pubellier and others, 1995). Other outcrops occur in the region but these have not been reviewed during this study.

The distribution of possible Jurassic deep marine shale is sparse but widespread, and when considered in light of the extensive intrusives and cover, it seems reasonable that these disperse outcrops can be interpreted as parts of a larger basin.

SONORA-SINALOA BATHOLITH

Batholithic scale magmatic activity is a common driving force in development of porphyry-style mineralization and mobilization of boron that results in formation of hydrothermal tourmaline during the final stages of magmatic crystallization of the batholithic mass. For these reasons, a better understand of the distribution of batholithic masses of the region might prove useful in understanding associated mineralization.

Following Triassic rifting and associated rift volcanism, Early to Middle Jurassic subduction initiated and produced a continental arc which extended from northern Sonora into central Mexico. Until dating is completed, it will be assumed that the andesitic volcanic rocks found in the marine sediments represent a Late Jurassic continuation of this same arc. In the area of Moris and Batopilas in southwestern Chihuahua, Early Cretaceous strata were either not deposited, or were stripped away before eruption of the Late Cretaceous andesitic volcanic sequence. After development of the Laramide (Late Cretaceous-Early Tertiary), volcano-intrusive magmatic complex, erosion locally exposed the batholithic phases. The extensive outpouring of the Sierra Madre Occidental Volcanic Province, during the Oligocene and Early Miocene, buried most of this erosion surface. Late Miocene extension during the opening of the Gulf of California broke the Tertiary cover, and subsequent erosion developed much of the presently observed batholith outcrop distribution.

This highly fragmented distribution complicates plotting the distribution of the batholithic masses. Regional compilation maps by Ortega-Gutierrez and others (1992) along with local mapping and associated age dating (McDowell and others, 2001) have improved our knowledge of the extent of Sonora-Sinaloa batholith. Limited modifications of the mapped distribution of batholitic rocks have resulted from the regional mapping of this study. The tighter control of batholith distribution produced by these field observations have aided in the integration of field data with the aeromagnetic data of Mexico (SGM, 2001).

Regional variation of magnetic fabric and intensity allows connecting fragmented outcrop localities and the projection of the batholiths into regions lacking outcrop. The magnetic data and radiometric age determinations (McDowell and others, 2001) indicate that distinct bodies of the batholithic complex exist with differing ages. The younger batholithic masses to the east (McDowell and others, 2001) are those that mostly intruded into proposed marginal-basin sediments. The resulting inferred distribution of the combined Sonora-Sinaloa Batholithic complex (Fig. 2), aids in the assessment of the possible association with B, Mo and Au mineralization.

GEOCHEMICAL DISTRIBUTION

Tourmaline, gold, molybdenum, nickel and cobalt distribution indicate a spatial correlation of these elements with the distribution of the deep-marine Jurassic sediments. The

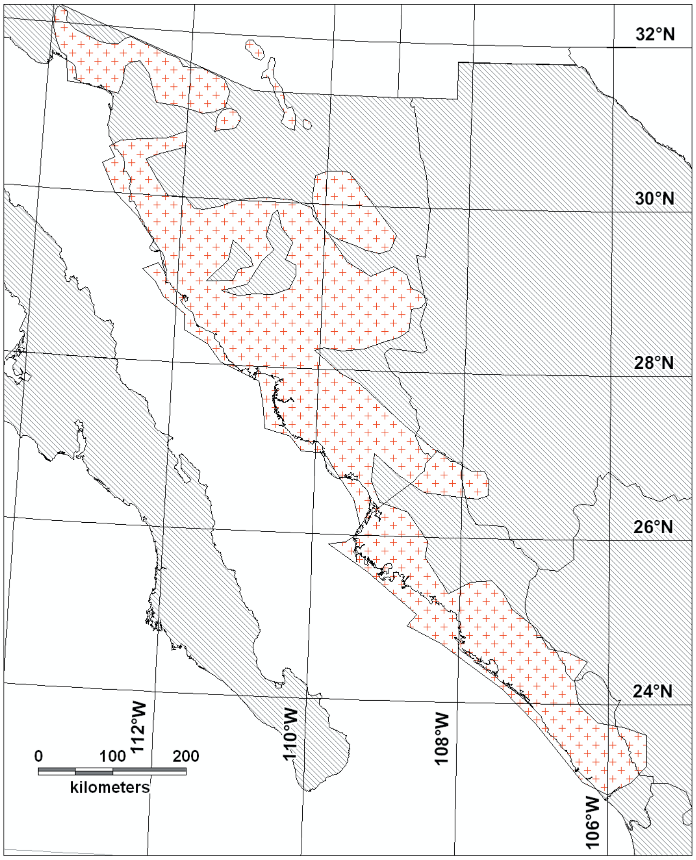

Figure 2. Fabrics and intensities from the aeromagnetic map of Mexico allow combining the many disconnected outcrops from the many maps of Mexico and regional studies into coherent masses that most likely represent the mostly buried distribution of the batholithic bodies (red pattern).

proposed extent of the Sonora-Sinaloa Batholith suggests that the intersection of the batholith with the sedimentary rocks is the most productive area for these types of mineralization. The mapped distribution partially reflects the degree of Tertiary volcanic cover along the eastern margin of the area of interest.

Tourmaline

Tourmaline distribution is based mostly on field observations and published descriptions (Table 1). The Western Mexican tourmaline province extends into southwestern Arizona with the Sierrita-Esperanza Mo-Cu district and runs at least as far south as central Sinaloa (Fig. 3). Significant accumulations of tourmaline occur throughout this region mostly in the form of breccia pipes and quartz-sericite veins. In the Sierrita-Esperanza porphyry system tourmaline occurs as disseminations in the Jurassic(?) Harris Ranch granodiorite. Along the Mulatos River, north of Mulatos, it occurs as a metamorphic halo around a felsic stock. Documented ages indicate an association with Laramide-age batholiths and coeval volcanism, with the possible exception of the Harris Ranch intrusion. Unpublished U-Pb data and field relationships have been interpreted to indicate that the Harris Ranch is Laramide but carries inherited Jurassic zircons (J. Spencer and C. Ferguson, Arizona Geological Survey, written commun., 2008).

Molybdenum and tourmaline occur together at Maria and La Colorada at Cananea, Sonora, and at Washington and Cumobabi, Sonora. Gold and tourmaline occur together at San Francisco, Sonora, in quartz-sericite veins; southeast of Arivechi, Sonora and southwest of Matarachic, Sonora, in breccia pipes and in quartz-sericite veins in the Morelos region of Chihuahua.

Tourmaline occurrences appear to be underreported in general, so this compilation (Table 1) derives in large part from the field observations of this study. A literature search and inquiries of geologists with abundant experience in the region added some systems and further verified that few significant localities occur outside of the proposed Guerrero Province.

Some tourmaline localities outside of the Guerrero Province occur within the region, such as at the Copper Creek deposit northeast of the San Manuel, Arizona porphyry deposit. A strong tourmaline locality west of the Jurassic basin, north of Caborca, is associated with a Laramide batholith that also cuts the Jurassic basin. Significant tourmaline occurs in Baja California but while it appears consistent with the general basin model, it occurs outside of the study area.

TABLE 1. TOURMALINE OCCURRENCES IN SOUTHWEST NORTH AMERICA

Name	State	Latitude	Longitude	Nature of occurrence	Metals	Age*	Visit	Reference
Copper Creek	ARIZ			Mineralized breccia pipes	Cu	61	Y	Lyons, this study
Harris Ranch	ARIZ			Disseminated			Y	Lyons, this study
Sierrita-Esperanza	ARIZ			Disseminated clusters	Mo, Cu	60-63	Y	
Cananea	SON			Mineralized breccia pipes	Cu, Mo	59	Y	
Maria	SON	30.026	-110.390	Pegmatitic breccia	Cu, Mo	60	Y	
La Colorada Pipe	SON			Pegmatitic breccia	Cu, Mo			
El Correo	SON	31.125	-111.166	Bx, Q-Tourm vns, bull qtz vns				Smith and others, 1987
San Francisco	SON	30.380	-111.155	Qtz tourm veins	Au		Y	
Cumobabi	SON	29.800	-109.817	Breccia matrix	Mo, Cu	59	Y	
Washington	SON			Breccia matrix	Cu, Mo		Y	Lyons, this study
Sierra San Ignacio	SON	28.720	-109.000	Breccia matrix	Cu, Au			
Rio Mulatos	SON	28.744	-108.760	Contact halo	Cu		Y	Lyons, this study
Santa Rosa	SON	28.442	-109.116	Breccia matrix			Y	Lyons, this study
Morelos	CHI	26.750	-107.750	Qtz tourm veins	Au		Y	Lyons, this study
Tameapa	SIN	25.633	-107.367	Stockwork and disseminated		50-57		
Tamazula	SIN	24.970	-106.950	Stockwork and disseminated				Cruz,1979
Malpica	SIN	23.250	-106.117	Breccia filling and stockwork	Cu > Mo	54		
Cosala	SIN	24.520	-106.683	Veins	Cu, Zn, Pb, Ag		Y	

*Re-Os ages from Barra and others, 2005

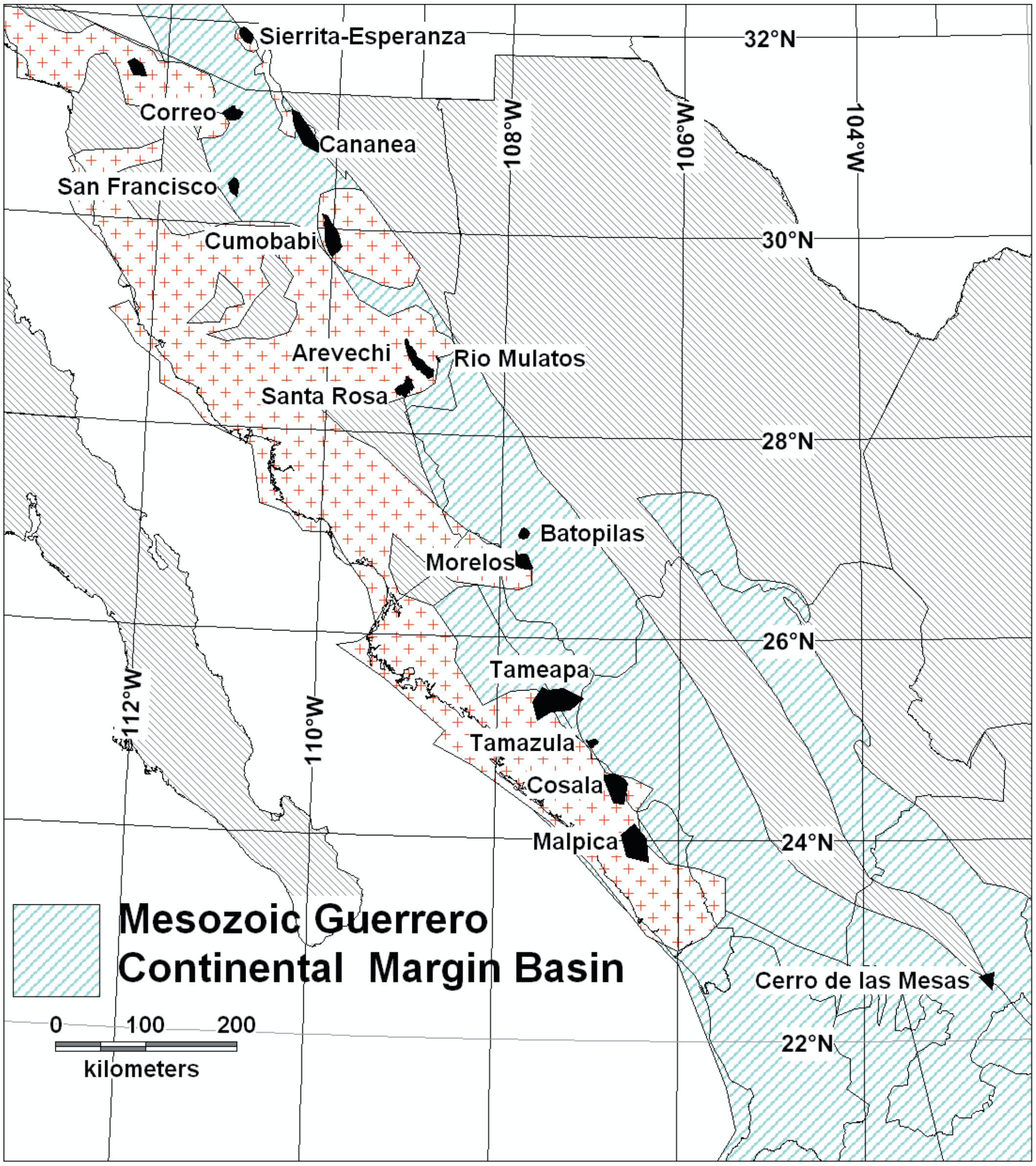

Figure 3. Tourmaline occurrences (in black) in Mexico and SW Arizona show a spatial correlation with the intersection of the proposed Guerrero Province (blue) and the Sonora-Sinaloa batholithic complex (red pattern).

Molybdenum

Most major Cordilleran molybdenum porphyry systems, associated with alkaline magmatism, occur well inboard of the related subduction but remain unknown in Mexico. A less important, but still significant, belt of Mo deposits occurs from Sierrita-Esperanza in Arizona through the Cumobabi District of central Sonora into southern Sonora. The majority of these Mo systems plot within the proposed limits of the Guerrero Province (Fig. 4). These deposits fall into the category of low fluorine Mo systems as proposed by Theodore and Menzie (1983).

Molybdenum grades in porphyry copper deposits of southwest North America appear to yield increased detail on the regional distribution of Mo resulting from their greater abundance (compiled in Table 2). Many problems exist with the numerical values reported. Reported Mo values, particularly as a byproduct, depend greatly on the relative economics of the metals at the time of evaluation and become problematic in attempting to compare metal distribution. Higher prices allow mining lower grades, thus bringing down the mined grade. Distribution of Cu and Mo in relation to each other within a deposit can also dramatically affect reported grades. The nature of the evaluated ore body bears directly on grade. At Cananea, the Maria pegmatitic lens and La Colorado pegmatitic-breccia pipe are very high grade, whereas the more dispersed Mo shells in porphyry system will yield lower grades but could have more contained metal.

TABLE 2. SOUTHWEST NORTH AMERICA PORPHYRY Cu-Mo GRADES

DEPOSIT	STATE	Cu(%)	Mo(%)	Tonnage	Tourmaline	SOURCE
Cumobabi	Son	0.250	0.2600	11	Y	Barton and others, 1995
Los Verdes	Son	0.200	0.2500	100		Long, 1995
Creston (Opedepe)	Son	0.150	0.1600			Valencia-Moreno and others, 2006
Washington	Son	1.710	0.0580	1	Y	Long, 1995
Sierrita-Esperanza	Ariz	0.330	0.0360	1168	Y	Long, 1995
Cuatro Hermanos	Son	0.431	0.0350			Barton and others, 1995
Twin Buttes	Ariz	0.900	0.0300	129		Long, 1995
Caridad	Son	0.404	0.0260	1500		Long, 1995
Cananea	Son	0.700	0.0200	1850	Y	Barton and others, 1995
Maria	Son	6.000	0.3600		Y	Wodzicki, 2001
La Colorada	Son	7.000	0.8000		Y	Wodzicki, 2001
Mission	Ariz	0.626	0.0190			Gilmour, 1982
Silver Bell	Ariz	0.770	0.0170			Gilmour, 1982
Florida-Barrigon	Son	0.300	0.0150			Barton and others, 1995
Pima	Ariz	0.480	0.0150			Gilmour, 1982
Copper Basin	Ariz	0.400	0.0145			Singer and others, 2002, 2005
Sacaton	Ariz	0.720	0.0140			Singer and others, 2002, 2005
Vekol Hills	Ariz	0.560	0.0140			Long, 1995
Hillsboro (Copper Flat)	NM	0.450	0.0130			Singer and others, 2002, 2005
Bagdad	Ariz	0.530	0.0120			Long, 1995
Johnson Camp	Ariz	0.489	0.0110			Singer and others, 2002, 2005
San Manuel-Kalamazoo	Ariz	0.680	0.0090	503		Long, 1995
Inspiration	Ariz	1.123	0.0090			Gilmour, 1982
Pinto Valley	Ariz	0.440	0.0090	258		Long, 1995
Morenci	Ariz	0.850	0.0090	957		Long, 1995
Santa Rita-Chino	NM	0.468	0.0080	439		Singer and others, 2002, 2005
Copper Cities	Ariz	0.530	0.0070	70		Long, 1995
Tameapa	Sin	0.400	0.0060		Y	Barton and others, 1995
Dos Pobres	Ariz	0.730	0.0060			Singer and others, 2002, 2005
Castle Dome	Ariz	0.330	0.0055			Singer and others, 2002, 2005
Helvetia	Ariz	0.552	0.0055			Singer and others, 2002, 2005
Ajo	Ariz	0.800	0.0050	388		Long, 1995
Ray	Ariz	0.950	0.0012	313		Long, 1995

If the Mo is only a byproduct, the reported Mo grade in a porphyry copper deposit will not always be representative of the contained Mo of the system. If the Cu and inner Mo ore shells show significant separation, the Mo may be under-represented by a lack of deeper drilling. Dos Pobres in eastern Arizona appears to have the reverse situation with higher Mo grades outside the Cu rich zone. Dos Pobres Mo grades are estimated to be between 0.01 and 0.001 % Mo based on grade contouring (Langton and Williams, 1982). The published bulk Mo grade for Cananea is 0.02% Mo but specific phases of the system such as the Colorado Pipe contain significantly higher grades (0.80 % Mo). The Maria deposit of the Cananea District contains 0.36 % Mo, but it is in reality only a pegmatitic phase of the Marta stockwork deposit for which I have not found published results.

Despite these limitations, plotting the Mo grades from Table 2 produces a strong spatial correlation with the proposed outline Guerrero Basin (Fig. 5). The change of Mo grades along the proposed Cananea Rift Fault is very dramatic, with the richer Mo deposits occurring along the margin and within the proposed Guerrero Basin.

There are some known Mo-porphyry systems that are not economic or remain untested. Chirimoyo, Durango, displays a broad suite of geologic features of a classic Colorado molybdenum deposit but does not contain enough Mo in the portion tested to be economic. Batopilas, Chihuahua, displays important potential as a Mo system but presently lacks testing directed at the Mo target.

Gold

Most geologists involved in mineral exploration in Mexico recognize a gold belt paralleling Mexico's west coast as an important feature in Mexico's mineral distribution. Table 3 attempts to list most Mexican Au deposits with published production and reserves greater than 100,000 ounces of Au (Albinson and others, 2001). In addition to these estimates of gold content, information compiled includes tourmaline associations and geologic setting. In Figure 5 the gold deposits are plotted with respect to the proposed Guerrero Marginal Rift Basin and the Sonora-Sinaloa batholith. Approximately 2/3 of total ounces of those deposits with greater than 1 million ounces Au occur within the proposed limits of the Guerrero Marginal Basin Province. Furthermore, it appears that most of those in the 100k to 1M ounce Au range also occur within the province.

Nickel and cobalt

These metals are typically associated with mafic igneous systems. Perez-Segura and others (2004) documented five small, low-grade, nickel-cobalt systems in western Mexico (Fig. 6). These occurrences are not economic but anomalous in their presence as epithermal systems. Extensive analytical results of mineralization at Batopilas reveal a small elevation of Ni and Co values in comparison with more typical hydrothermal systems.

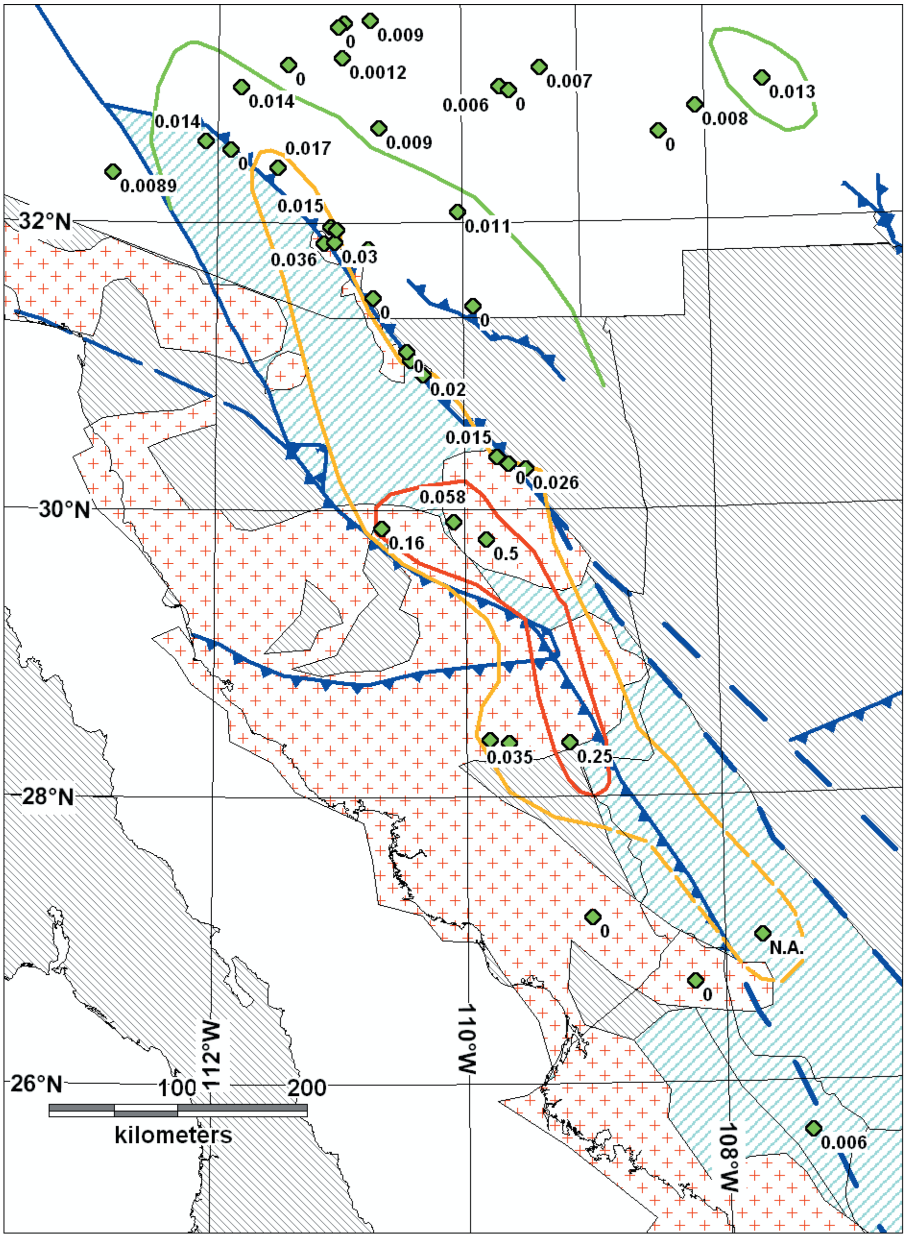

Figure 4. Contouring the published Mo grades of Arizona, New Mexico and Northwest Mexico illustrates the correlation between of the proposed Jurassic Guerrero basin and Mo grades. This contoured data accentuates the proposed Cananea Rift Fault. Inside red contour is > than 0.02 % Mo, inside the orange contour is > than 0.015 % Mo and inside the green contour is > than 0.01 % Mo (other fields as in Figure 2).

DISCUSSION

The spatial distribution of Au, B, Mo, Ni, and Co suggests a possible association between these elements and the Jurassic sediments of the proposed Guerrero Province. Boron and to a lesser degree molybdenum are known to be enriched in shale basins (Table 4). Au, Ni, and Co were initially thought to be related to the increased presence of oceanic crust to the west in the extended marginal rift basin, but there is also evidence that the sediments associated with submarine volcanism, as observed at Batopilas and Moris, may start out more enriched in these elements than the oceanic crust (Wedepohl, 1978). Because of the very low background levels of Au, there is generally a lack of data on gold distribution in crustal rocks. Gold on average is three times more abundant in basalt than granite (Table 4) but even at 6 ppb Au remains near normal detection limits and may lack true significance.

Relation of tourmaline to shale basins. Analysis of boron levels in a variety of rock types indicates that shale on average contains an order of magnitude greater amounts of B than other B-bearing rocks. Two possible paths for these elevated B levels include derivation of B from subducted shale or the assimilation of shale from marginal basins by rising magmas. The spatial relationship of both the outcropping batholiths and tourmaline occurrences suggests that shale assimilation is probably the overriding control and the more dispersed tourmaline occurrences may relate to subducted shale. A gold-tourmaline association occurs at the San Francisco Gold Mine, in the Matarachic breccia pipes, and in the Morelos district quartz-tourmaline veins.

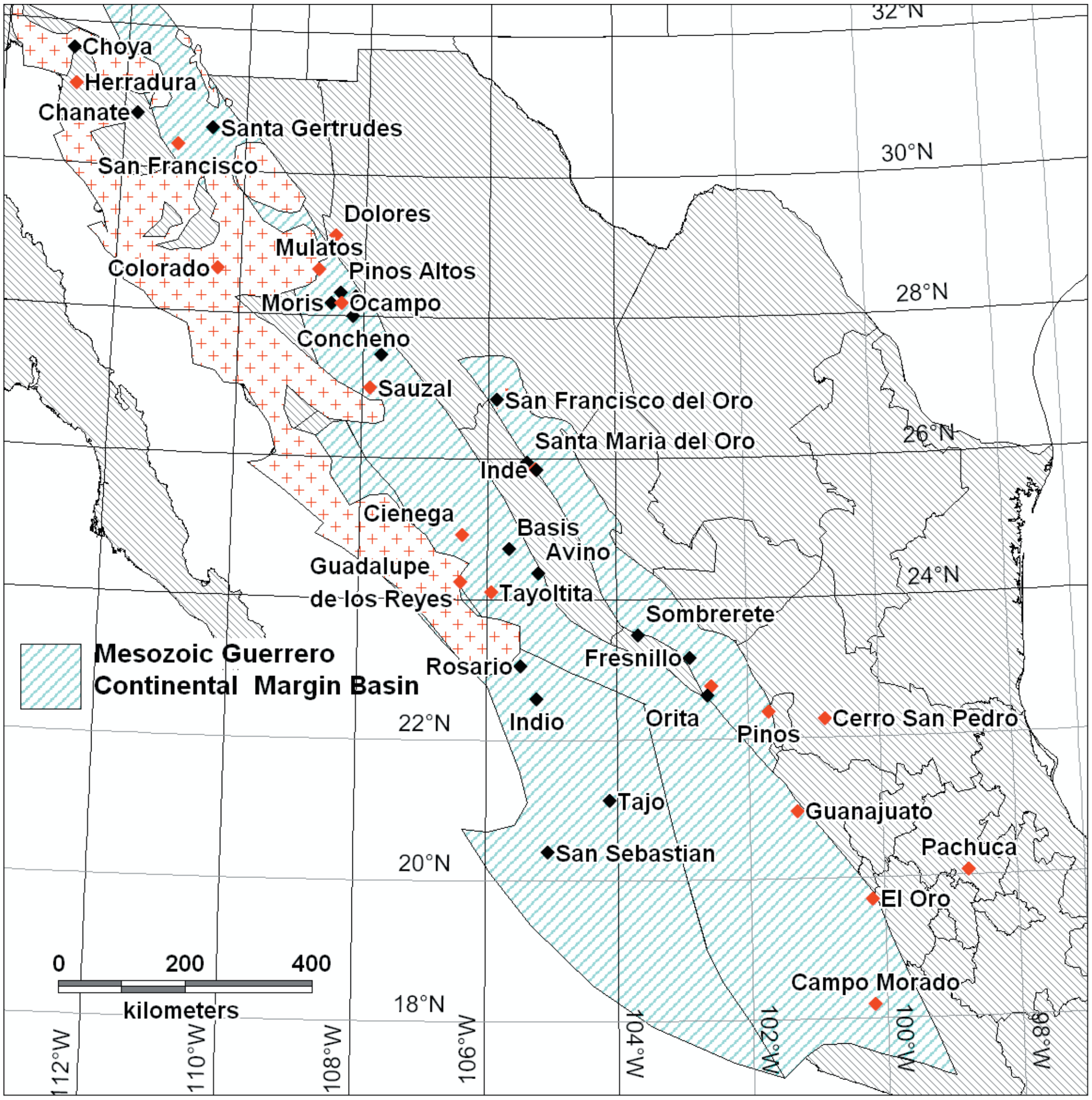

Figure 5. A significant portion of Mexico's gold deposits show a strong spatial correlation with the proposed Jurassic marginal basin. Red diamonds indicate deposits with ≥ 1 M ozs. Au production and reserves and black diamonds denote between 1M ozs. and 0.1 M ozs. (other fields as in Figure 2).

Molybdenum

Despite the difficulties of using mine assay data to accurately portray Mo levels in the various deposits, it appears that systematic differences do occur depending on the location of the porphyry mineral system in relation to the proposed Guerrero Marginal Rift Basin Province. Boron- and molybdenum-enriched magma systems spatially associated with Jurassic marine shale and submarine volcanism may reflect magmatic assimilation of B- and Mo-enriched shale. This would suggest that the indicated basin is not superficial but of significant volume. The halo of intermediate Mo values around the proposed basin between 0.01 % and 0.015% Mo may reflect magmatic systems assimilating both continental and anomalous basin-fill crust.

Gold

The distribution of Au deposits in Mexico in relation to the proposed Guerrero Marginal Rift Basin Province suggests a possible relationship between the basin and Au mineralization. Approximately 2/3 of gold plotted lies within or along the basin margins. The proposed limits of the Guerrero Province include a large portion of the Mexican crust and the province forms a significant wall rock to Mexico's Laramide and younger magmatism. Therefore the spatial correspondence between Au and the Guerrero Basin may not be surprising. The abrupt drop in Au abundance across the east margin of the basin, the Cananea rift fault, northward into Arizona suggest that there may be more than just the coincidence of subduction associated magma and basin location.

The increased amounts of oceanic crust under an

TABLE 3. SIGNIFICANT Au DEPOSITS OF MEXICO

Deposit	State	M oz Au	Tectonic Setting	Geologic setting	Reference
Avino	Durango	0.203	Guerrero Basin	Tertiary rhyolite vent	Albinson and others, 2001
Bacis	Durango	0.422	Guerrero Basin	Tertiary rhyolite vent	Albinson and others, 2001
Campo Morado	Guerrero	1.500	Guerrero Basin	Volcanogenic massive sulfide	Oliver and others, 2001
Cerro San Pedro	San Luis Potosi	4.000			Petersen, 2001
Chanate	Sonora		Papago		
Choya	Sonora		Papago		
Cienega	Durango	1.000	Guerrero Basin	Tertiary rhyolite flow dome	Albinson and others, 2001
Colorado	Sonora	5.750	Caborca		Albinson and others, 2001
Concheno	Chihuahua	0.438	Parral-Proano		Albinson and others, 2001
Dolores	Chihuahua	2.450	Guerrero Basin		Overbay and others, 2001
Fresnillo	Zacatecas	0.108	Guerrero Basin		Albinson and others, 2001
Guadalupe de los Reyes	Sinaloa	1.300	Guerrero Basin	Dacite dome	Albinson and others, 2001
Guanajuato	Guanajuato	5.000	Guerrero Basin		Albinson and others, 2001
Herradura	Sonora	2.000	Papago		
Inde	Durango		Parral-Proano		
Indio	Sinaloa	0.156	Guerrero Basin		Albinson and others, 2001
Maguarichic	Chihuahua	0.206	Guerrero Basin		Albinson and others, 2001
Moris	Chihuahua		Guerrero Basin	Ter. intrusion cutting Jur. sed	
Mulatos	Sonora	2.500	Guerrero Basin	Oligocene rhydacite dome	
Ocampo	Chihuahua	2.800	Guerrero Basin	Oligocene rhydacite dome	Gammon Lake web site
Orito	Zacatecas	0.625	Parral-Proano		Albinson and others, 2001
Oro	Mexico State	9.500	Guerrero Basin		Albinson and others, 2001
Pachuca	Pachuca	6.250			Albinson and others, 2001
Pinos	Zacatecas	5.625	Parral-Proano		Albinson and others, 2001
Rosario	Sinaloa	0.117	Guerrero Basin		Albinson and others, 2001
San Francisco	Sonora	1.000	Guerrero Basin		
San Francisco del Oro	Chihuahua	0.312	Parral-Proano		Albinson and others, 2001
San Sebastian	Jalisco		Guerrero Basin		
Santa Gertrudes	Sonora		Guerrero Basin		Alba, 1998
Santa Maria del Oro	Durango		Parral-Proano		
Sombrerete	Zacatecas	0.330	Parral-Proano		Albinson and others, 2001
Suazal	Chihuahua	2.000	Guerrero Basin		
Taxco	Guerrero	0.280	Guerrero Basin		Albinson and others, 2001
Tayoltita (San Dimas)	Durango	9.750	Guerrero Basin		Clarke, 1988
Zacatecas	Zacatecas	2.110	Parral-Proano		Albinson and others, 2001

extended crust may play a role in increasing the gold content of magmas if they assimilate this oceanic crust as well. Detrital Au in a cratonic marginal basin is another possible Au source, but significant potential cratonic detrital Au sources are not known in the region.

Nickel and cobalt

Nickel-cobalt-rich systems along a rifted margin may represent a greater oceanic crustal component with greater distance from the unextended craton. Ocean sediments deposited in submarine volcanic environments also appear significantly enriched in Ni and Co (Wedepohl, 1978).

CONCLUSIONS

Cretaceous through Holocene cover limits earlier Mesozoic outcrops and creates a major challenge in understanding the Triassic and Jurassic history of western Mexico. The increasing number and focused distribution of probable Jurassic marine outcrops along Mexico's west coast encourages the integration of these outcrops into a unified basin from Arizona to at least as far south as Durango. Although a gap exists in the knowledge between Sinaloa and Durango, and southwest Mexico south of the Trans-Mexican Volcanic Belt, the continuity of the Parral-Proaño overthrust, which thrusts sediments out of this basin, and the lithologic and age correlation between the north and south regions, support the presence of one continuous Mesozoic marginal basin along Mexico's west coast, the Guerrero Marginal Rift Basin. More support for extending the basin at least as far south as Durango comes from the coincident distribution of tourmaline, Mo and Au within the proposed boundaries of the basin.

Magma evolution certainly affects metal distribution but newer more complete metal distribution maps produce different patterns than those proposed by Clark and others (1982). An improved understanding of the basement distribution in western Mexico highlights spatial correlations between B, Mo, Au, Ni, and Co, and the resulting proposed marginal rift basin. The proposed basin also parallels the plate boundary and the crustal composition is distinctly different from the adjacent crust. The spatial association of these elements with the Jurassic Guerrero Marginal Rift basin probably has multiple causes, but the presence of submarine volcanism in the basin is potentially a major contributor to the metal character of mineral systems later formed within the basin limits.

Table 4. Average element background levels of B, Mo, Ni, Co and Au for various crustal rocks in ppm

Element	Crust	Basalt	Granite	Shale	Ocean Ridge Sediments	Sandstone	Carbonate	Sea H_2O
B	10	5	15	130	N.A.	35	20	4.6
Mo	1	1.5	2.0	2-2.6	N.A.	0.2	0.4	0.01
Ni	75	150	0.5	68-95	160-320	2	20	0.002
Co	25	48	1	19-20	80-160	0.3	0.1	0.0001
Au	0.004	0.006	0.002	N.A.	N.A.	N.A.	N.A.	0.00004

From: Taylor, 1964; Turekian and Wedepohl, 1961; Wedepohl, 1978

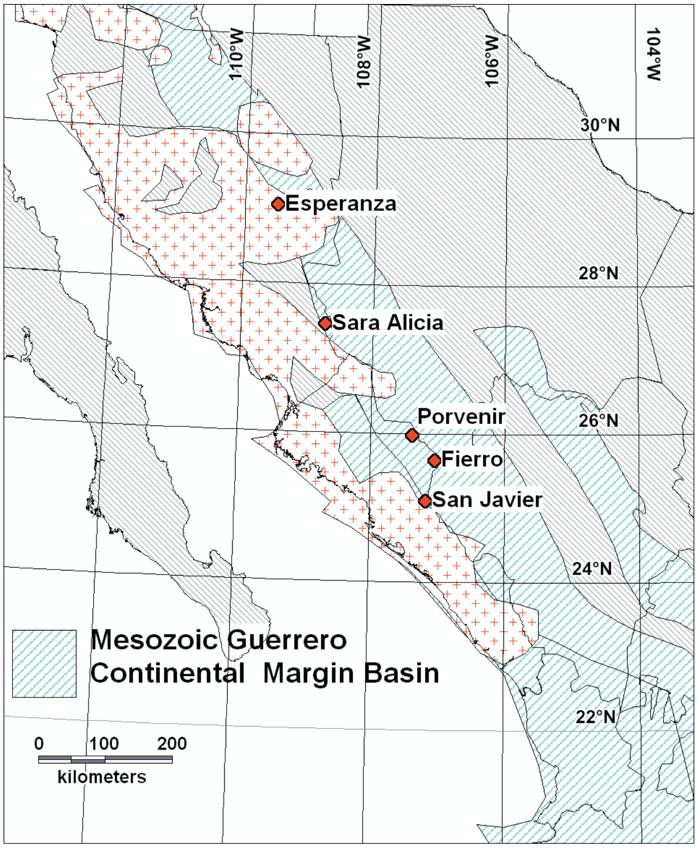

Figure 6. The Ni and Co deposits (red diamonds) of northwest Mexico (Perez-Segura and others, 2004), although sparse, show spatial correlation with the proposed Jurassic marginal basin (shaded blue).

Although still debated, evidence is strong that rising, subduction-associated magmas must derive much of their melt volume from assimilation of the host crust. If these magmas rise through a crust anomalous in a certain suite of elements, the resulting magmas should also become anomalous in these elements. Many other factors such as timing, volatile chemistry and content, structural controls and permeability will influence the final nature of magma-driven mineral systems, but the chemical composition of assimilated crust appears to be potentially a significant influence.

If the correlation between the proposed Mesozoic marginal rift basin, the Guerrero Province, and the distribution of mineralization can be further documented, it will present a significant insight into the development of metallogenic provinces.

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