K-Ar and F-T ages for syntectonic mid-Tertiary volcanosedimentary sequences associated with the Catalina core complex and San Pedro trough in southern Arizona

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K-Ar AND F-T AGES FOR SYNTECTONIC MID-TERTIARY VOLCANOSEDIMENTARY SEQUENCES ASSOCIATED WITH THE CATALINA CORE COMPLEX AND SAN PEDRO TROUGH IN SOUTHERN ARIZONA

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Geologic features that define the Catalina core complex and San Pedro trough near Tucson in southeastern Arizona were produced by Tertiary extensional tectonism that accompanied crustal thinning (Davis and Hardy, 1981; Davis, 1983; Spencer, 1984). Stratigraphic and structural relations of syntectonic sedimentary and associated volcanic sequences of mid-Tertiary age help constrain the inferred timing and geometry of extensional deformation (Dickinson, 1984; Dickinson and Shafiqullah, 1986). This paper presents unpublished K-Ar and fission-track age determinations that control the chronostratigraphy of key mid-Tertiary successions, and sets the new data in the context of previously available information.

We infer that mid-Tertiary strata within the area have been affected principally by extensional deformation. Consequently, local or gentle folding that can be interpreted as evidence of crustal shortening (Keith and Wilt, 1985) is ascribed instead to accommodation of kinematics associated with crustal thinning by extensional fault systems having irregular geometric configurations (Naruk and others, 1987).

ANALYTICAL INFORMATION

Analytical procedures discussed by Damon and others (1983) were used in this study (constants: $\lambda_\beta = 4.963 \times 10^{-10}$ yr^{-1}, $\lambda_\epsilon = 0.581 \times 10^{-10}$ yr^{-1}, $\lambda = 5.544 \times 10^{-10}$ yr^{-1}, $^{40}K/K = 1.167 \times 10^{-4}$ atom/atom). Fission-track age determinations were done using methods described by Naeser (1976) at the fission-track laboratory of the U.S. Geological Survey in Denver and at the University of Arizona. Error estimates were made at 2 standard deviations by combining Poisson errors of fossil, induced, and neutron dosimetry counts.

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DISCUSSION

MORPHOSTRUCTURAL TERMINOLOGY

The term "Catalina core complex" is adopted here (after Rehrig and Reynolds, 1980) to designate the Cordilleran core complex denoted also by several other more cumbersome names ("Santa Catalina-Rincon-Tortolita crystalline complex" of Keith and others, 1980; "Catalina-Rincon metamorphic core complex" of Bykerk-Kauffman and Janecke, 1987). The term "San Pedro trough" is adapted here from oral usage developed by J. D. Lowell (personal communication, 1984) during his classic study of the tilted San Manuel and Kalamazoo porphyry copper orebodies (Lowell, 1968).

The San Pedro trough is an elongate structural depression flanked on the southwest by the Catalina core complex, with mid-Tertiary mylonitic fabric along its southwest flank, and associated uplands lying farther north (fig. 1); to the northeast, the faulted front of the relatively undeformed Galiuro Mountains block is the breakaway zone for the detachment fault system that bounds the core complex. Tilted homoclines of mid-Tertiary strata are extensively exposed along the San Pedro trough, where they lie unconformably beneath erosional remnants of younger Cenozoic basin fill, and are also locally exposed within eroded uplands of varied character to the southwest.

STRATIGRAPHIC NOMENCLATURE

The stratigraphic framework of mid-Tertiary horizons within the San Pedro trough, and flanking the Catalina core complex, has been obscured by proliferation of local formational names, some unpublished but widely cited, and by inadvertent miscorrelations. The legend of figure 1 indicates the lithostratigraphic terminology preferred here.

A consistent set of Oligocene-Miocene formations, including local members and facies, can be mapped throughout the San Pedro trough and the uplands north of the Catalina core complex: mid-Oligocene Mineta Formation, upper Oligocene Galiuro Volcanics, Oligocene-Miocene Cloudburst Formation, and lower Miocene San Manuel Formation. Chronostratigraphic correlations and facies relationships remain unclear in detail between these units and various subunits of the Oligocene-Miocene Pantano Formation in the Tucson Basin and Cienega Gap south of the Catalina core complex. Overlying gently deformed Miocene-Pliocene sequences are designated variously in different modern drainage basins; their stratigraphy is discussed here only as necessary to clarify the structural and stratigraphic relationships of the underlying mid-Tertiary units.

DATA PRESENTATION

Our new analytical results are given in the following sections. Previously published K-Ar ages relevant for discussion of the new data are compiled in tables 1–3. Locations of our samples and those of table 2 are plotted on figure 1. Figure 2 displays the array of ages for mid-Tertiary volcanic rocks demonstrating a late Oligocene pulse of intermediate volcanism. Figure 3 shows the distribution of key mid-Tertiary stratigraphic sections correlated in figure 4, which also indicates the past stratigraphic usages of previous authors.

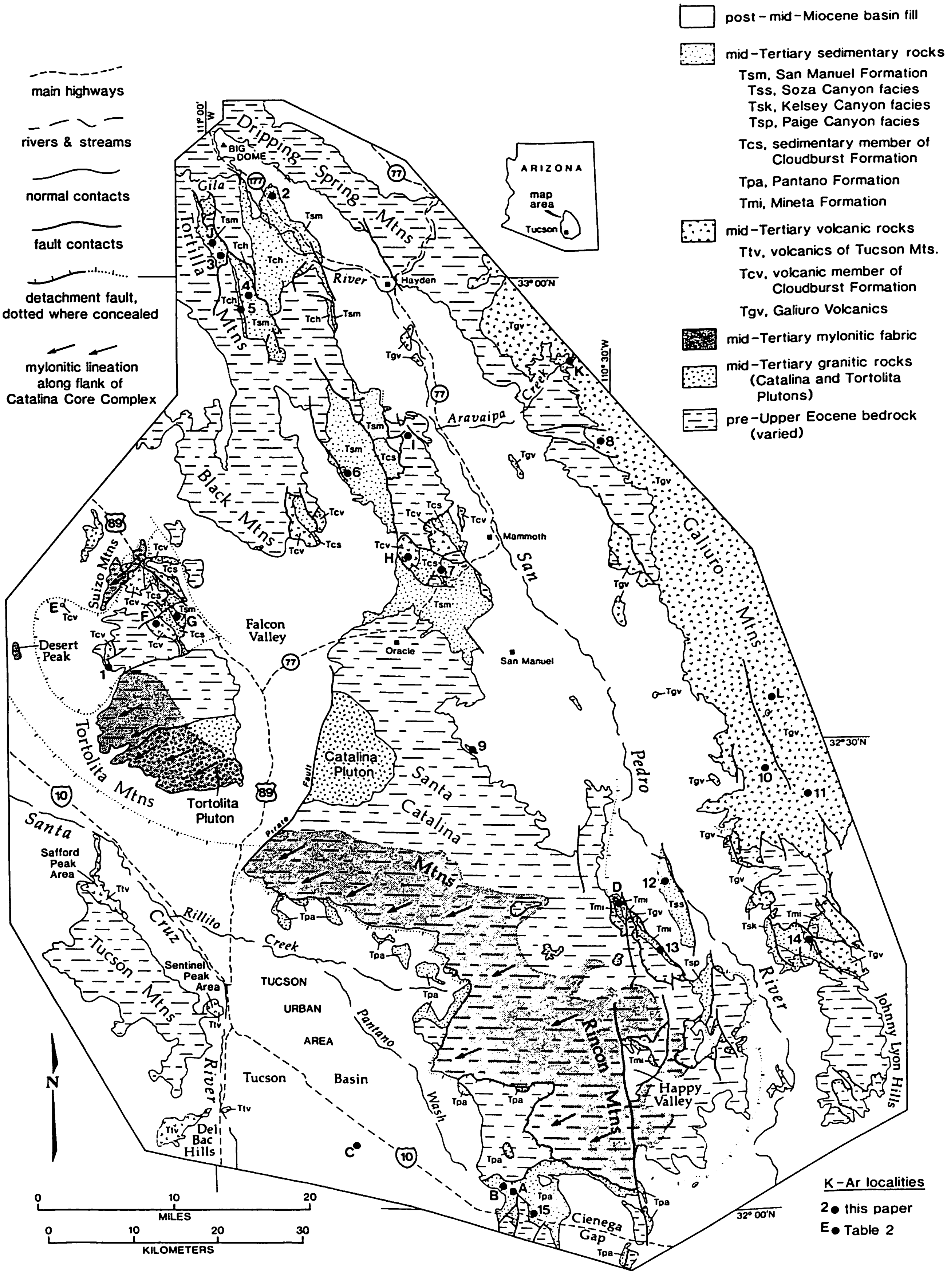

FIGURE 1. Geologic map of Catalina core complex and San Pedro trough showing areal distribution of tilted homoclines of dated mid-Tertiary volcanosedimentary successions in relation to older bedrock exposures and younger basin fill (after Dickinson, 1987, 1988). Local trends of mylonitic lineation along southwest flank of Catalina core complex from Banks (1980), Budden (1975), Davis (1980), Drewes (1977), and our unpublished data.

PUBLISHED K-Ar AGES

TABLE 1. Published K-Ar ages for mid-Tertiary volcanic fields of Tucson and Galiuro Mountains

See fig. 1 for general locations. (w) whole rock, (b) biotite, (s) sanidine, (p) plagioclase, (f) feldspar. All ages cited in recalculated form reported by Reynolds and others (1986) using most accurate currently known decay constants (numbers from their listing in brackets). Each data set (A, B, C, D) given in apparent stratigraphic order from oldest to youngest.

		Age (Ma)
A. Galiuro Volcanics of Galiuro Mountains (Creasey and Krieger, 1978; coordinate sanidine K-Ar ages for several samples are consistently 1–3 Ma younger):		
ash-flow tuff of lower part [#849]	(b)	28.9 ± 0.8
rhyolite dike in lower part [#817]	(b)	28.1 ± 0.8
Holy Joe (ash-flow tuff) Member [ave. of #785 & #786]	(b)	27.3 ± 0.8
Tuff of Bear Springs Canyon [#661]	(b)	24.4 ± 0.7
Aravaipa (ash-flow tuff) Member [#752]	(b)	26.4 ± 1.0
Hells Half Acre Tuff Member [#703]	(b)	25.3 ± 0.7
B. Safford Peak area of northern Tucson Mountains (Bikerman and Damon, 1966):		
Rillito andesite (ignimbrite?) [#946]	(b)	39.4 ± 1.3
Safford Peak bedded tuff [#697]	(b)	25.2 ± 1.4
Contzen Pass vitrophyre (ignimbrite?) [#760]	(w)	26.6 ± 1.2
Safford Peak andesite (ignimbrite?) [#832]	(b)	28.5 ± 1.9
Safford Peak dacite neck [#690]	(b)	25.1 ± 0.9
C. Sentinel Peak area of southern Tucson Mountains (Bikerman and Damon, 1966; Shafiqullah and others, 1978):		
Turkey Track lava, A Mtn [#839]	(p)	28.6 ± 2.7
basaltic andesite, Sentinel Peak [#798]	(w)	27.6 ± 1.2
bedded air-fall tuff, A Mtn [#793]	(f)	27.4 ± 0.9
dacitic ash-flow tuff, A Mtn [#751]	(s)	26.4 ± 0.9
basaltic andesite, A Mtn [#655]	(w)	24.2 ± 0.5
basaltic andesite, Tumamoc Hill [#627]	(w)	23.7 ± 0.5
D. Del Bac Hills south of Tucson Mountains (Percius, 1968):		
Turkey Track lava, San Xavier [#796]	(w)	27.6 ± 0.8
basaltic andesite, Black Mountain [#712]	(w)	25.4 ± 0.7
basaltic andesite, Black Mountain [#656]	(w)	24.3 ± 1.0
basaltic andesite, Martinez Hill [#649]	(w)	24.1 ± 0.9
basaltic andesite, Martinez Hill [#699]	(w)	25.2 ± 0.7

TABLE 2. Published K-Ar ages for mid-Tertiary volcanic rocks near Catalina core complex and San Pedro trough

Plotted by letter designation on fig. 1. (w) whole rock, (h) hornblende, (b) biotite, (p) plagioclase. All ages cited in recalculated form reported by Reynolds and others (1986) using most accurate currently known decay constants (numbers from their listing in brackets).

	Age (Ma)	
A. impure rhyolite tuff within Pantano Formation near Cienega Gap [#857]	(b) 29.5 ± 0.9	Shafiqullah and others, 1978
B. Turkey Track andesitic lava of Pantano Formation near Cienega Gap [#681]	(p) 24.9 ± 2.6	Shafiqullah and others, 1978
C. andesitic lava from depth of 2,420–2,426 m in Exxon State 32-1 well [#641]	(w) 23.9 ± 0.6	Eberly and Stanley, 1978
D. Turkey Track andesitic lava in Galiuro Volcanics overlying type Mineta Formation at Mineta Ridge near Bar LY Ranch [#773]	(p) 26.9 ± 2.4	Shafiqullah and others, 1978

TABLE 2. Published K-Ar ages for mid-Tertiary volcanic rocks near Catalina core complex and San Pedro trough (continued)

	Age (Ma)	
E. quartz latite lava of The Huerfano butte west of Suizo Mountains [#694 & #617]	(h) 25.1 ± 0.4 (b) 23.5 ± 0.4	Banks and others, 1979
F. quartz latite lava near Chief Butte north of Tortolita Mountains [#765]	(b) 26.7 ± 0.5	Banks and others, 1979
G. olivine-bearing basalt lava at base of San Manuel Formation in Three Buttes area [#535]	(w) 21.0 ± 0.5	Banks and others, 1979
H. basaltic lava near base of type Cloudburst Formation in Cloudburst Wash near Mammoth [#826]	(w) 28.3 ± 0.6	Shafiqullah and others, 1978
I. rhyolite dike intruding Precambrian basement in Putnam Wash west of mouth of Aravaipa Creek [#597 = #576]	(b) 22.8 ± 0.7	Marvin and Dobson, 1979
J. rhyodacite tuff near top of tuffaceous sandstone interval in San Manuel Formation of Ripsey Wash [#414]	(b) 17.5 ± 1.0	Berry and others, 1976
K. air-fall tuff in Whitetail Conglomerate below Galiuro volcanics in Aravaipa Canyon [#907]	(b) 33.5 ± 0.6	Krieger and others, 1979
L. andesite in andesite-rhyodacite subunit of lower part of Galiuro Volcanics [#786]	(b) 27.2 ± 0.8	Creasey and Krieger, 1978

TABLE 3. Published K-Ar ages for mid-Tertiary volcanic rocks assigned to the Pantano Formation or its correlatives in the region south of Catalina core complex and San Pedro trough

See fig. 1 for general locations. (w) whole rock, (b) biotite, (s) sanidine, (p) plagioclase. All ages cited in recalculated form reported by Reynolds and others (1986) using most accurate currently known decay constants (numbers from their listing in brackets).

	Age (Ma)	
dacite in Pantano Formation along west flank of Empire Mountains near Martinez Ranch in Davidson Canyon [#843]	(b) 28.7 ± 1.1	Marvin and others, 1973
Turkey Track andesitic lava within Helmet Fanglomerate at Twin Buttes on north flank of Sierrita Mountains [#885]	(p) 31.4 ± 1.2	Shafiqullah and others, 1978
tuff intercalated within Helmet Fanglomerate near Twin Buttes on north flank of Sierrita Mountains [#836]	(b) 28.6 ± 2.6	Damon and Bikerman, 1964
rhyolitic tuff* [#949]	(b) 39.8 ± 1.5	Marvin and others, 1973
ash-flow tuff* [#808]	(s) 27.8 ± 0.7	Shafiqullah and others, 1978
ash-flow tuff* [#768]	(s) 26.7 ± 0.6	
basalt* [#675]	(w) 24.8 ± 1.0	

*Intercalated with conglomerate, red arkose, and freshwater limestone near Babocomari Ranch between Whetstone and Huachuca Mountains

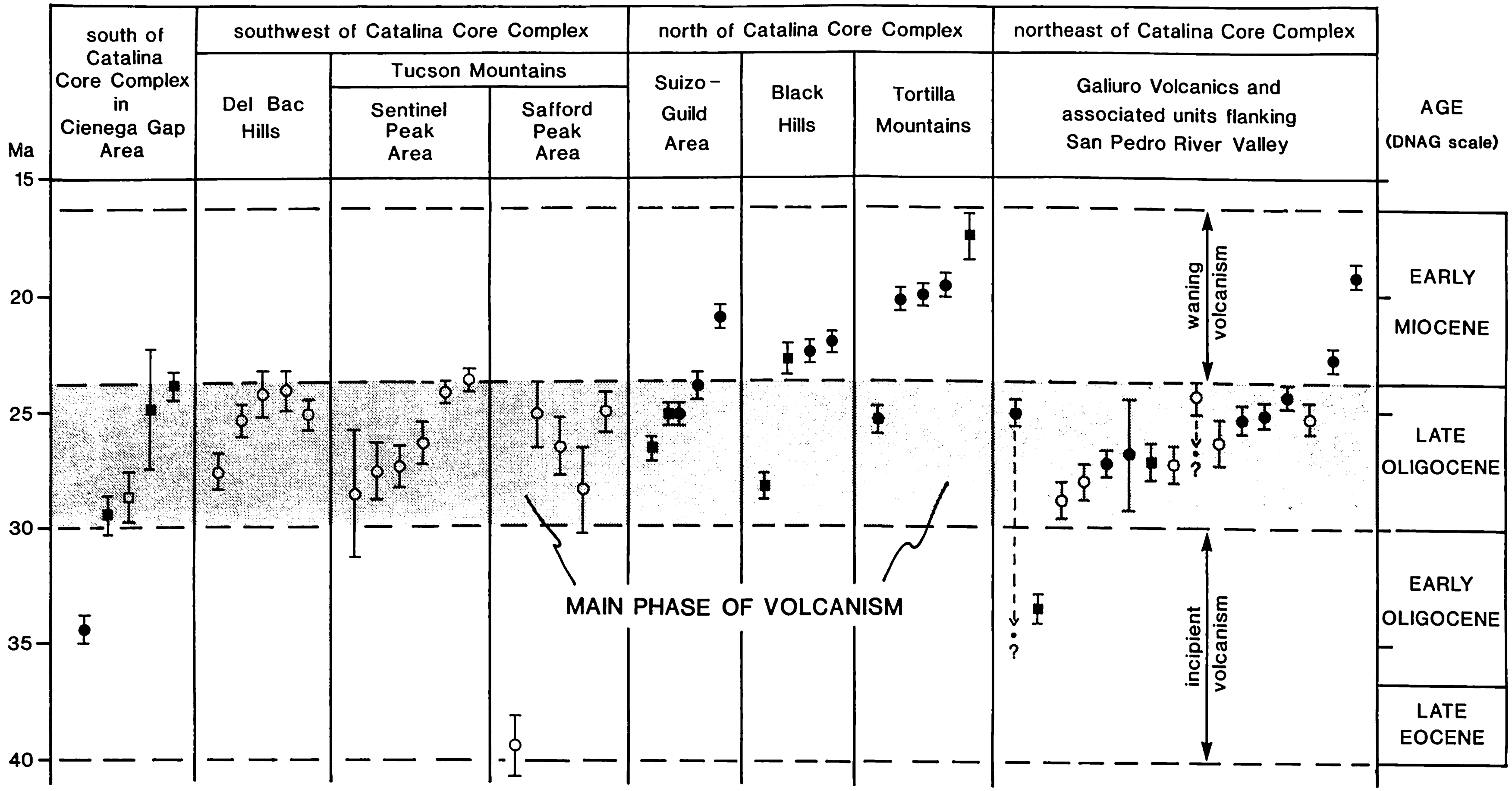

FIGURE 2. Geochronologic array of K-Ar dates for Tertiary volcanic rocks in region (10^4 km^2) surrounding Catalina core complex and San Pedro trough; points from each subarea plotted in observed or inferred stratigraphic order from left to right (solid circles, this paper; open circles, table 1; solid squares, table 2; open squares, table 3; queried dot, probable true age of spurious date). Points within field of incipient volcanism represent Rillito Andesite (table 1), ash-flow tuffs beneath Pantano and Mineta Formations, and airfall tuff within Whitetail Conglomerate underlying Galiuro Volcanics. Main phase of volcanism represented by volcanics of Tucson Mountains (and Del Bac Hills), volcanic lower member of Cloudburst Formation, and Galiuro Volcanics, together with more distal equivalents intercalated within Pantano Formation and Hackberry Wash facies of Cloudburst Formation. Points within field of waning volcanism represent sparse tuffs and lavas intercalated within or overlying sedimentary strata in sedimentary member of Cloudburst Formation, San Manuel Formation, Apsey Conglomerate Member of Galiuro Volcanics, and Hell Hole Conglomerate overlying Galiuro Volcanics. Black Hills lie west of Mammoth and Tortilla Mountains lie southwest of Hayden; Suizo (Mountains)-Guild (Wash) area lies north of Tortolita Mountains (fig. 1).

MID-TERTIARY MAGMATISM

To the southwest and east of the Catalina core complex, extensive mid-Tertiary volcanogenic successions in the Tucson and Galiuro Mountains and associated uplands were erupted mainly in late Oligocene time. Correlative strata in the volcanic lower member of the Cloudburst Formation exposed to the north and northwest of the Catalina core complex record the same pulse of volcanism. This main phase of local volcanism was coincident in timing with the culmination of mid-Tertiary magmatism throughout southeastern Arizona (24–30 Ma according to Shafiqullah and others, 1978). In areas distant from the principal volcanic centers, sedimentary sequences contain correlative lavas and tuffs intercalated at selected horizons.

A few samples dated from the region surrounding the Catalina core complex reveal that incipient pre-mid-Oligocene volcanism preceded the main eruptive phase. Within the study area, lower Oligocene felsic tuffs occur locally at or near the base of some mid-Tertiary volcano-sedimentary sequences. Precursors of the mid-Tertiary volcanic episode also evidently include some rocks as old as late Eocene in age.

Within the Catalina core complex, the closely related Catalina and Tortolita granitic plutons record an episode of mid-Tertiary plutonism (Creasey and others, 1977). Available Rb-Sr and U-Pb radiometric data suggestive of intrusion at about 26 ma (Reynolds and others, 1986, #713 and #755) imply that these granitic bodies were emplaced during the main late Oligocene pulse of local magmatism. Seven of eleven reported K-Ar ages for the plutons (Reynolds and others, 1986) are only slightly younger (24–26 Ma, Oligocene), and the remainder can be interpreted with confidence or by inference as cooling dates (21–23 Ma, Miocene). However, the data are permissive of plutonism continuing locally into earliest Miocene time.

Following the prominent late Oligocene pulse of magmatism, waning volcanism continued intermittently through much of early Miocene time. Thin olivine-bearing mafic lavas of earliest Miocene age (21–23 Ma) and lower Miocene silicic tuffs (18–22 Ma) are intercalated with, underlie, or overlie conglomeratic sedimentary sequences that either rest depositionally upon or overlap thick upper Oligocene volcanic sequences. The local presence of these volcanogenic horizons produced by the waning phase of mid-Tertiary volcanism affords the only effective means of establishing the ages of different stratigraphic units within the varied Miocene succession.

No reliably dated middle Miocene volcanic rocks occur within the study area and mid-Miocene stratigraphic relationships are consequently uncertain. Nearly flat-lying vitric tuff layers of upper Miocene age (5–7 Ma) occur in lacustrine facies of the Quiburis Formation within the San Pedro trough (Scarborough, 1975), but the age of deeper, unexposed levels of the essentially undeformed basin fill remains undocumented. Within the interior of the San Pedro trough, we infer an upward transition from older tilted strata, preserved now only in buried half-grabens, to younger untilted strata at some unexposed horizon of mid-Miocene age.

MID-TERTIARY SEDIMENTATION

Within the study area, scattered exposures of tilted mid-Tertiary sedimentary strata are separated by expanses of pre-Oligocene bedrock and areas covered by overlapping basin fill. Most are conglomeratic alluvial fan and braided stream deposits with intercalated sandy successions, but extensive lacustrine deposits occur locally, particularly in the Mineta and Pantano Formations. Megabreccia bodies formed by landslides and debris avalanches are also common in several of the units (Krieger, 1977). Correlations between separate exposures of mid-Tertiary sedimentary formations can be made with full confidence only where associated volcanic rocks or intercalated pyroclastic layers have been dated radiometrically.

The Pantano Formation of Cienega Gap and the Tucson Basin probably contains correlatives of all the sedimentary units mapped farther north. Locally exposed at the base of the Pantano section, but disconformable beneath the overlying sedimentary strata, is a lens of 34–35 Ma rhyolitic ash-flow tuff with a maximum observed thickness of 15 m (Balcer, 1984). We infer that a comparable lens of similar ash-flow tuff up to 25–50 m thick at the base of the type Mineta Formation may be a product of the same ignimbritic eruptions (the 25 Ma K-Ar age is clearly spurious from local stratigraphic relations). The lengths of the time gaps represented by disconformable contacts at the top of these lower Oligocene ignimbrites are unknown, but could readily be as much as about five million years, for the oldest dated horizons in the Pantano Formation, and in the generally correlative Helmet Fanglomerate, are about 30 Ma.

Intercalated within sedimentary strata near the middle of the Pantano Formation, as exposed in Cienega Gap, is a 25 Ma porphyritic intermediate lava of "Turkey-Track" type (Cooper, 1961) correlative with the Galiuro Volcanics, which overlie the Mineta Formation concordantly in the San Pedro trough. Pantano strata below this volcanic horizon are inferred to be correlative, at least in part, with the Mineta Formation, whereas Pantano strata above this volcanic horizon are inferred to be correlative, in whole or in part, with thick sections of the Cloudburst and San Manuel Formations exposed still farther north.

Deposition of the Pantano Formation may thus have spanned much or all of the interval from mid-Oligocene to mid-Miocene time, whereas the Mineta Formation was apparently deposited entirely within some part of mid-Oligocene time. In Redington Pass, lying between the Santa Catalina and Rincon Mountains of the Catalina core complex, structurally complex extensional klippen lying above detachment fault surfaces (Benson, 1981) include isolated exposures of mid-Tertiary redbeds regarded here as Mineta Formation but mapped previously as Pantano Formation (Thorman and Drewes, 1981). We treat similar strata in analogous structural position at Happy Valley between the Rincon and Little Rincon Mountains as Mineta Formation as well, but they were also referred to the Pantano Formation by Drewes (1974). Within the Mineta Formation, widely distributed clasts derived from the Galiuro Volcanics, or a similar source, suggest that the onset of post-Mineta volcanism was time-transgressive and that the Mineta Formation and the Galiuro Volcanics may in part be facies equivalents.

A lens of volcaniclastic strata ("Whitetail Conglomerate") beneath the Galiuro Volcanics in Aravaipa Canyon contains a 33.5 Ma air-fall tuff comparable in age to air-fall tuff in the Whitetail Conglomerate that lies depositionally beneath Miocene Apache Leap Tuff near the Ray Mine north of the Gila River (33.2 ± 0.6 Ma of Banks and others, 1972; #903 of Reynolds and others, 1986). The relationship between these lower Oligocene strata and the Mineta Formation exposed farther south remains uncertain, but they may be correlative in part.

The volcanic lower member of the Cloudburst Formation exposed north of the Catalina core complex is composed of lavas and breccias lithologically similar to counterparts in

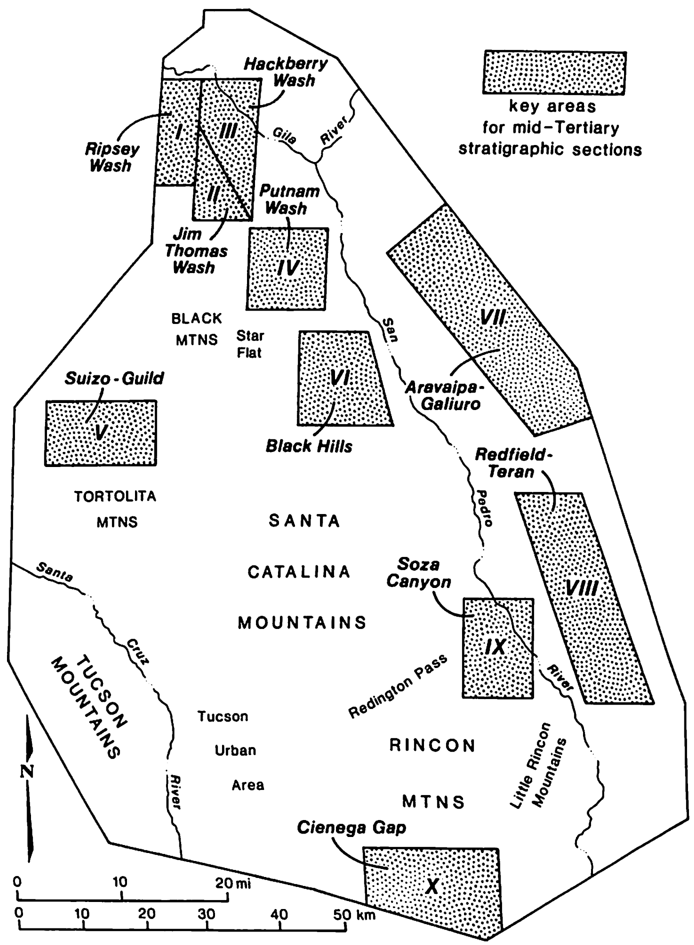

FIGURE 3. Location map.

Footnotes: [1]"Ripsey Wash sequence" of Schmidt (1971) assigned to San Manuel Formation by Cornwall and Krieger (1975a,b); [2]main part of "Hackberry formation" of Schmidt (1971) mapped as lower part of San Manuel Formation by Krieger (1974b) and Cornwall and Krieger (1975a) but first correlated with Cloudburst Formation by Heindl (1958, p. 168); [3]includes upper part of "Hackberry formation" (Schmidt, 1971), mapped as upper part of San Manuel Formation by Cornwall and Krieger (1975a), and lower part of "Big Dome Formation" of Krieger and others (1974) as mapped by Cornwall and Krieger (1975a); [4]main part of "Big Dome Formation" of Krieger and others (1974) as mapped by Cornwall and Krieger (1975a); [5]lower part of "Hackberry formation" of Schmidt (1971) mapped as lower part of San Manuel Formation by Krieger (1974b) and Cornwall and Krieger (1975a); [6]upper part of "Hackberry formation" of Schmidt (1971) mapped as upper part of San Manuel Formation by Krieger (1974b) and Cornwall and Krieger (1975a); [7]mapped as lower part of San Manuel Formation by Krieger (1974d); [8]assigned to San Manuel Formation by Krieger (1974c); [9]Tertiary "volcanic rocks" of Banks and others (1977) assigned here to Cloudburst Formation by analogy with equivalent strata exposed at Star Flat in Black Mountains (Krieger, 1974c); [10]"older Tertiary sedimentary deposits" of Banks and others (1977) formerly referred to correlative Pantano Formation by Barter (1962); [11]"younger Tertiary sedimentary deposits" of Banks and others (1977) formerly referred to correlative Pantano Formation by Barter (1962); [12]"volcanic unit" of Heindl (1963) or "volcanics" of Creasey (1965) in Cloudburst Formation, which was regarded erroneously by both authors as probably of Late Cretaceous or early Tertiary age based on information then available; [13]"fanglomerate unit" of Heindl (1963) or "fanglomerate" of Creasey (1965) in Cloudburst Formation as mapped by Weibel (1981); [14]members of San Manuel Formation of "Gila Group" as mapped locally by Heindl (1963), but regarded jointly by Creasey (1965) as "lower member of Gila Conglomerate," although usage of either "Gila Group" or "Gila Conglomerate" was later abandoned, at least locally, by Krieger and others (1974); [15]as proposed by Heindl (1963) but regarded as "upper member of Gila Conglomerate" by Creasey (1965); [16]as mapped by Krieger (1968a); [17]as named by Krieger (1968a) underlying-andesite of Table Mountain (Krieger, 1968b); [18]as mapped by Simons (1964); [19]complex internal stratigraphy discussed by Creasey and Krieger (1978) and Creasey and others (1981); [20]as mapped by Grover (1982, 1984) passing in part along strike into strata mapped locally as Threelinks Conglomerate by Cooper and Silver (1964) and same as "Teran beds" of Melton (1965); [21]granitic-clast "Paige gravels" of Grover (1982, 1984) or "Kelsey beds" of Melton (1965) designated here (as Tske) after Dickinson (1986, 1987) to distinguish the strata from correlative metamorphic-clast "Paige gravels" of Lingrey (1982) designated differently (as Tspg) by Dickinson (1987) in Little Rincon Mountains east of Happy Valley (fig. 3); [22]as mapped by Agenbroad (1967) and subsequent workers; [23]of Chew (1952, 1962) and Clay (1970) but referred to correlative Pantano Formation by Thorman and Drewes (1981); [24]as mapped by Dickinson and Olivares (1987); [25]volcanic-clast "Soza beds" of Chew (1952) and Clay (1970) designated here (as Tssz) after Dickinson (1987) and including reworked 25.4 Ma volcaniclast contained within a prominent megabreccia body; [26]"Banco beds" of Chew (1952) and Clay (1970); [27]of Brennan (1957, 1962) and Finnell (1970) as mapped by Drewes (1977) and Balcer (1984); [28]"Nogales Formation" of Drewes (1977).

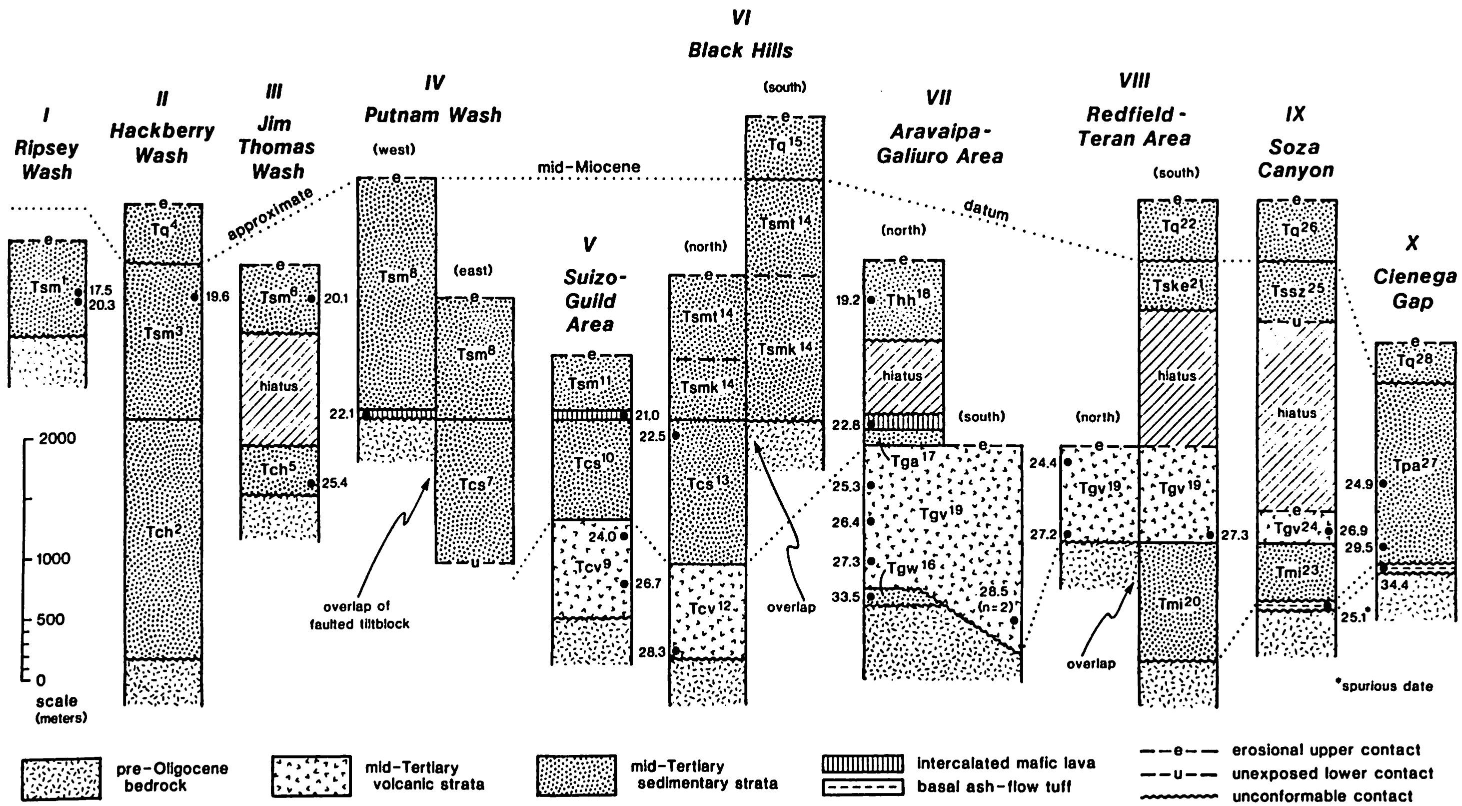

FIGURE 4. Key stratigraphic sections (thicknesses approximate) of syntectonic mid-Tertiary (mainly upper Oligocene and lower Miocene) volcanosedimentary sequences of San Pedro trough and nearby flanks of Catalina core complex. Numbered dots denote K-Ar ages (see text and tables).

Unit symbols: Tpa, Pantano Formation; Tmi, Mineta Formation; Tgv, Galiuro Volcanics (Tgw, basal "Whitetail Conglomerate" in Aravaipa Canyon; Tga, Apsey Conglomerate Member); Tc, Cloudburst Formation (Tcv, volcanic lower member; Tcs, sedimentary upper member; Tch, Hackberry Wash facies in Tortilla Mountains); Tsm, San Manuel Formation (Tsmk, Kannally Member; Tsmt, Tucson Wash Member; Tssz, Soza Canyon facies; Tske, Kelsey Canyon facies; Tspg, Paige Canyon facies); Thh, Hell Hole Conglomerate of Aravaipa Valley east of Galiuro Mountains; Tq, Quiburis Formation of post-mid-Miocene basin fill.

the Galiuro Volcanics farther east, and both assemblages of intermediate volcanics are late Oligocene in age. Further work may succeed in establishing detailed correlations between specific volcanic units. For now, different stratigraphic names are retained for the two sequences because lavas and breccias of the Galiuro Volcanics are intercalated with and overlain by extensive sheets of ash-flow tuff, whereas the volcanic member of the Cloudburst Formation generally lacks intercalated ash-flow tuff and is overlain gradationally by thick conglomeratic beds in the sedimentary upper member of the Cloudburst Formation. Conglomeratic strata of the Cloudburst Formation, including the Hackberry Wash facies, commonly display red coloration that is generally absent from overlying beds that are otherwise lithologically similar in the San Manuel Formation. Thin lavas and tuffs interbedded locally with sedimentary strata of the Cloudburst Formation indicate that Cloudburst sedimentation spanned the Oligocene-Miocene time boundary.

Exposed contacts between sedimentary sequences of the Cloudburst and San Manuel Formations are typically concordant, with no evidence of significant hiatus at the contact, although the mean dip of Cloudburst strata is consistently greater than the mean dip of overlying San Manuel beds where the two form parts of the same homoclinal successions. Locally, however, the formational contact is unconformable, displaying mappable angularity. Moreover, strata of the San Manuel Formation commonly overstep preserved remnants of the Cloudburst Formation to rest directly on pre-Oligocene rocks. We infer from these observed stratigraphic and structural relationships that both units are syntectonic sequences deposited while faulting, tilting, and accompanying erosion were underway during extensional deformation. Cloudburst strata were evidently preserved only within downdropped grabens where they were protected from erosion. Continuation of sedimentation produced essentially conformable contacts with the overlying San Manuel Formation where the Cloudburst Formation was not eroded. Elsewhere, correlative San Manuel beds gradually overlapped parts of eroded horsts or tiltblocks along buttress unconformities as erosion wore down uplifted areas while uninterrupted sediment accumulation built up overall sediment thicknesses in adjacent basins or subbasins.

Data are inadequate to establish whether the contact between redbeds of the Cloudburst Formation and gray or tawny strata of the overlying San Manuel Formation is diachronous from one area of exposure to another. The probable diagenetic origin of the coloration in the older unit implies that the contact cannot be strictly isochronous, but the stratigraphic positions of dated lavas and tuffs apparently constrain all exposed contacts to some lower part of the lower Miocene interval (20–22 Ma). In two areas, olivine-bearing mafic lavas (21–22 Ma) occur at or near the base of the San Manuel Formation. These volcanic marker units bear close lithologic resemblance to the olivine-bearing "andesite of Table Mountain" (22.8 Ma) at the top of the Galiuro Volcanics farther east. We infer that the nearly synchronous eruption of these olivine-rich lavas, described variously as basalt or andesite, represented a diagnostic petrogenetic stage in the structural evolution of the study area. The limits of analytical error for the three dated samples almost overlap at about 22 Ma, the age that we thus assign nominally to the base of the San Manuel Formation. The thin Apsey Conglomerate Member of the Galiuro Volcanics beneath the "andesite of Table Mountain" is evidently equivalent in age to some upper part of the Cloudburst Formation. The Hell Hole Conglomerate, which overlies the Galiuro Volcanics unconformably near the head of Aravaipa Canyon along the eastern flank of the Galiuro Mountains (outside the study area), is apparently correlative at least in part with the San Manuel Formation but is essentially flat-lying except where deformed locally by an abrupt monoclinal flexure above a subsurface fault (Simons, 1964).

In the Gila River valley, about 10 m of pink ash-flow tuff intercalated within the upper part of the San Manuel Formation is regarded on lithologic grounds as a distal finger of Apache Leap Tuff (correlation first suggested to us by P. E. Damon). This ignimbrite unit, formerly known as "Superior Dacite," is distributed over a large region to the northwest where it reaches a maximum thickness of nearly 1,000 m (Peterson, 1968). Our biotite K-Ar age of 19.6 ± 0.5 Ma is analytically indistinguishable from 20 Ma K-Ar ages reported for Apache Leap Tuff from the type area near Superior: (a) 19.9 ± 0.6 Ma by Creasey and Kistler (1962) [#486 of Reynolds and others, 1986] and (b) 20.4 ± 0.9 Ma by Damon and Bikerman (1964) [#506 of Reynolds and others, 1986]. Air-fall tuff layers that are also about 20 Ma in the San Manuel Formation of the nearby Tortilla Mountains are interpreted here as co-ignimbrite air-fall ashes produced by Apache Leap eruptions. A somewhat younger (17.5 Ma) air-fall tuff farther upsection in the San Manuel Formation of the Tortilla Mountains is correlative with the Sleeping Buffalo Rhyolite exposed farther north across the Gila River where Creasey and others (1983) reported an age of 17.5 ± 0.7 [#415 of Reynolds and others, 1986]. Fission-track ages for impure tuffs within the San Manuel Formation are imprecise, but are concordant with available K-Ar ages and imply that no part of the sequence is younger than 15 Ma.

The lower Miocene San Manuel Formation is commonly overlain unconformably by upper Miocene or younger beds of the Quiburis Formation. The intra-Miocene duration of the hiatus between the two formations is nowhere closely controlled by available data. The Quiburis Formation, together with overlying terrace and pediment gravels, forms the largely undeformed basin fill of the San Pedro trough. Strata displaying approximately depositional attitudes are extensive in exposures of the Quiburis Formation, although steeper dips occur locally near offsetting faults, compactional drape over basement irregularities accounts for anomalous local dips in other areas, and mild warping of uncertain origin has caused widespread but gentle subregional tilting of Quiburis strata elsewhere.

In widely separated localities, the contact between moderately tilted San Manuel and Quiburis strata is concordant. In these areas, the uppermost San Manuel Formation includes one or more reddish paleosol horizons. As deformation waned and tilting of syntectonic strata gradually ended, periods of downweathering marked by widespread soil development may have interrupted sedimentation producing condensed sections. As subsequent aggradation of the Quiburis Formation progressively masked the residual relief of fault-block topography within the San Pedro trough, homoclines of tilted mid-Tertiary strata and intervening tilt-blocks and horsts of older bedrock were eventually buried beneath the gradually thickening basin fill.

At its type locality, Big Dome on Mineral Creek near the Gila River, the Big Dome Formation of Krieger and others (1974) is regarded here as laterally equivalent in both age and lithology to the Quiburis Formation of the San Pedro River valley to the southeast. The name Quiburis has precedence (Heindl, 1963) and is adopted here in preference to the name Big Dome. In local areas near the Gila River between Big Dome and the mouth of the San Pedro River, some strata mapped as lower Big Dome Formation by previous workers are regarded here as part of the San Manuel Formation, which underlies the Quiburis Formation. However, near the mouth of the San Pedro River, strata mapped as Big Dome Formation along the Gila River valley (Banks and Krieger, 1977) pass laterally without break into contiguous strata mapped as Quiburis Formation along the San Pedro River valley (Krieger, 1974a). In our view, all basin-fill successions laterally contiguous with the Quiburis Formation of the San Pedro trough should be designated by that formational name. We also refer to the Quiburis Formation some strata previously mapped as Nogales Formation in Cienega Gap.

The Quiburis Formation onlaps both flanks of the San Pedro trough and contains detritus derived from the diverse bedrock units exposed in the adjoining uplands. Within the Quiburis Formation, coarse alluvial fan facies deposited along the flanks of the San Pedro trough grade laterally inward to and prograde above finer grained braidplain and lacustrine facies that occupied the depositional axis of the San Pedro trough (Agenbroad, 1967; Utley, 1980). Mammalian remains and magnetostratigraphic studies within the Quiburis and St. David Formations of the San Pedro River valley indicate that deposition of basin fill had begun by late Miocene time and continued through much of Pliocene time (Smith, 1967; Johnson and others, 1975). Erosion of the basin fill initiated by integration of the Gila River drainage system (Cooley, 1968) locally exhumed tilt-blocks in Pliocene or later time to expose Paleozoic to Oligocene strata.

The Cenozoic stratigraphy of the Tucson Basin southwest of the Catalina core complex is poorly known because stratigraphic relationships are hidden in the subsurface. Probable equivalents of the Quiburis Formation were termed "Tinaja beds" by Davidson (1973) but include multiple disconformities (Anderson, 1987). Exposures of the underlying Pantano Formation in foothills and pediments around the northeastern periphery of the Tucson Basin were described by Voelger (1953) and Pashley (1966) as "Rillito I" ("Rillito II" and "Rillito III" being roughly synonymous with "Tinaja beds"). In the basin depocenter, Eberly and Stanley (1978) report 2,220 m of Miocene and younger basin fill above 1,440 m of 24 Ma volcanics and underlying Oligocene redbeds of the Pantano Formation. The subsurface section of Miocene and younger basin fill is comparable in aggregate thickness to sequences of tilted and dissected strata in the San Manuel and Quiburis Formations of the San Pedro trough. The thickness of intercalated volcanics and redbeds underlying this Neogene basin fill is comparable to that of the Pantano Formation as exposed in Cienega Gap. Uncertainties and ambiguities in the ages of strata penetrated by the well are currently under study by H. W. Peirce and the junior author.

DEFORMATIONAL HISTORY

The chronostratigraphic relations provide no insight into the complex geometry of mid-Tertiary extensional deformation. However, the geochronologic data do set constraints on the timing of that deformation.

In the Mineta and lower Pantano Formations, coarse conglomeratic strata derived from source rocks exposed nearby in uplifted blocks of rugged relief, and associated lacustrine facies ponded in discrete local basins, imply that mid-Tertiary tectonism was initiated by 30 Ma (mid-Oligocene time). However, broad areas display no record of this incipient extensional tectonism. Instead, laterally extensive upper Oligocene (24–30 Ma) volcanic fields contain no significant thicknesses of coarse clastic strata. Plutonic equivalents of these mid-Tertiary volcanics were emplaced within the same general time frame, and have been exposed largely through subsequent tectonic denudation of the Catalina core complex.

Shortly after eruption, the widespread mid-Tertiary volcanic blanket was intricately disrupted by extensional faulting, and allowed downfaulted portions of the volcanic field to be covered by thick sequences of coarse conglomeratic strata. Sedimentation of this kind occupied much or all of lower Miocene time (16?-or 18–24 Ma).

After about mid-Miocene time, much reduced rates of extensional deformation were accompanied by progressive aggradation that buried the rugged mid-Tertiary paleotopography beneath basin fill along the San Pedro trough and within the Tucson Basin. During this phase of basin filling, steep faulting blocked out prominent range fronts locally, but stratal tilting had become rare. Pliocene or younger dissection of basin fill has occurred on a grand scale along the San Pedro trough, but has been comparatively slight in the Tucson Basin.

In summary, extensional deformation began in late Oligocene time (24–30? Ma), was most intense during part of early Miocene time (16?–24 Ma), waned during mid-Miocene time, and has proceeded at much reduced rates since then. Numerous reset or partially reset K-Ar and fission-track ages (Reynolds and others, 1986) range downward from 40 to 20 Ma for various mylonitic protoliths within the Catalina core complex. These data suggest that mid-Tertiary movements on the ductile shear zone associated with the main detachment fault also culminated in early Miocene time but do not preclude initial deformation as early as late Eocene time.

SAMPLE DESCRIPTIONS

1. *UAKA 85-70* K-Ar
Feldspar concentrate from trachyandesite (32°34.83′N, 111°7.55′W; Tortolita Mountains quad., Pinal Co., AZ) of volcanic lower member of Cloudburst Formation (fig. 4, col. V) exposed in fresh bulldozer cut on southernmost peak of Owlhead Buttes as basal Tertiary unit of the Guild Wash detachment system. *Analytical data:* K = 6.625, 6.690, 6.664, 6.697%; ^{40}Ar = 278.4, 278.7, 277.8, 280.2 pm/g; atm. Ar = 12.3, 12.6, 12.7, 12.6%.

(feldspar) 24.0 ± 0.6 Ma

2. *UAKA 82-104* K-Ar
Quartz latite ash-flow tuff (33°4.94′N,110°55.12′W; Kearny quad., Pinal Co., AZ) intercalated within upper part of San Manuel Formation (fig. 4, col. II) ("Big Dome Formation" of Cornwall and Krieger, 1975a). *Analytical data:* K = 7.136, 7.136, 7.148, 7.136%; ^{40}Ar = 245.6, 243.0, 244.0, 240.7 pm/g; atm. Ar = 35.5, 35.7, 35.6, 35.9%. K-Ar ages reported by Banks and others (1972) for a sample collected nearby from the same horizon are 14.7 ± 0.3 and 17.6 ± 0.3 m.y. for biotite and hornblende, respectively (#333 and #418 of Reynolds and others, 1986).

(biotite) 19.6 ± 0.5 Ma

3. *UAKA 83-7 and 83-170* K-Ar and fission-track
Waterlaid silicic air-fall tuff (33°1.32′ and 1.33′N, 110°58.95′W; Kearny quad., Pinal Co., AZ) in lensoid bed near base of tuffaceous middle member of San Manuel Formation as exposed along upper Ripsey Wash (fig. 4, col. I). *Analytical data:* biotite: K = 6.083, 6.098, 6.037, 6.068%; ^{40}Ar = 215.0,

214.8, 215.7, 215.5 pm/g; atm. Ar = 49.2, 49.1, 49.0, 49.1%; zircon, DF-5118, DF-5110, 17 grains: P_S = 1.94 x 10^6 tracks/cm² (2543 tracks counted); P_i = 5.16 x 10^6 tracks/cm² (3379 tracks counted); neutron dose = 9.08 x 10^{14} N/cm²; uranium = 180 ppm; counted by C. W. Naeser and M. Shafiqullah; apatite, DF-5117, 13 grains: P_S = 0.05 x 10^6 tracks/cm² (112 tracks counted); P_i = 1.09 x 10^6 tracks/cm² (1161 tracks counted); neutron dose = 7.1 x 10^{15} N/cm²; uranium = 6.1 ppm; counted by M. Shafiqullah.

K-Ar (biotite) 20.3 ± 0.5 Ma
F-T (zircon) 20.4 ± 1.4 Ma
F-T (apatite) 20.6 ± 4.2 Ma

4. *UAKA 76-133* K-Ar
Silicic air-fall tuff (32°58.75'N, 110°56.71'W; Crozier Peak quad., Pinal Co., AZ) intercalated within synclinally folded San Manuel Formation as white ash bed 2 m thick exposed along Jim Thomas Wash (fig. 4, col. III). *Analytical data:* chloritized biotite: K = 6.238, 6.176%; ^{40}Ar = 211.0, 213.8, 220.4, 225.2 pm/g; atm. Ar = 57.5, 56.9, 55.9, 57.6%; hornblende: K = 0.566, 0.568%; ^{40}Ar = 23.23, 23.23, 22.92 pm/g; atm. Ar = 52.7, 52.7, 54.1%; plagioclase: K = 0.786, 0.779%, ^{40}Ar = 34.98, 34.98 pm/g (plagioclase crystals contain excess argon). Krieger (1974b) reported K-Ar ages of 18 Ma on biotite and 24 Ma on sanidine for a sample from the same outcrop (#496, #613, #721 of Reynolds and others, 1986; after Scarborough and Wilt, 1979).

(biotite) 20.1 ± 0.5 Ma
(hornblende) 23.4 ± 0.6 Ma
(plagioclase) 25.6 ± 0.6 Ma

5. *UAKA 83-73* K-Ar
Olivine-bearing basaltic andesite lava (32°57.89'N, 110°57.44'W; Crozier Peak quad., Pinal Co., AZ) intercalated within Hackberry Wash facies of Cloudburst Formation along upper Jim Thomas Wash (fig. 4, col. III) about 10 m stratigraphically above basal unconformity (mapped as "andesitic volcanic rocks" within San Manuel Formation by Krieger, 1974b). *Analytical data:* K = 2.851, 2.873, 2.855, 2.855, 2.860, 2.843, 2.860%; ^{40}Ar = 127.1, 126.6, 126.8, 127.0, 127.0, 126.1, 125.9, 126.1 pm/g; atm. Ar = 14.7, 14.0, 14.1, 14.0, 14.4, 14.2, 15.1, 15.0%.

(groundmass feldspar) 25.4 ± 0.6 Ma

6. *UAKA 81-11* K-Ar
Olivine-bearing basaltic andesite lava (32°47.3'N, 110°49.9'W; Putnam Wash quad., Pinal Co., AZ) along tributary to Camp Grant Wash between Blood Sucker Wash to the N and Palmer Wash to the S at base of San Manuel Formation (fig. 4, col. IV). *Analytical data:* K = 0.781, 0.780, 0.783%; ^{40}Ar = 30.19, 29.83, 30.18 pm/g; atm. Ar = 40.2, 40.8, 40.3%. Age reported here first cited by Weibel (1981) (#569 of Reynolds and others, 1986).

(groundmass feldspar) 22.1 ± 0.5 Ma

7. *UAKA 81-28* K-Ar
Rhyolite clast 2.5 km SW of Red Hill near Mammoth (fig. 4, col. VI) (32°41.0'N, 110°42.3'W; Mammoth quad., Pinal Co., AZ) in rhyolitic breccia and tuff-breccia of the uppermost Cloudburst Formation. *Analytical data:* K = 3.960, 3.963%; ^{40}Ar = 154.8, 156.2, 156.5 pm/g; atm. Ar = 8.2, 8.3, 8.2%. Age first cited by Weibel (1981) (#584 of Reynolds and others, 1986).

(feldspar) 22.5 ± 0.5 Ma

8. *UAKA 76-96* K-Ar
Andesite lava (32°49.74'N, 110°31.26'W; Holy Joe Peak quad., Pinal Co., AZ) from base of massive flow in middle part of andesite of Table Mountain, which is the uppermost unit of Galiuro Volcanics overlying Apsey Conglomerate Member (fig. 4, col. VII). *Analytical data:* K = 1.785, 1.798, 1.781%; ^{40}Ar = 69.66, 71.96, 71.56 pm/g; atm. Ar = 12.0, 11.6, 11.8% (#595 of Reynolds and others, 1986; after Scarborough and Wilt, 1979).

(groundmass feldspar) 22.8 ± 0.5 Ma

9. *UAKA 85-69* K-Ar
Dacite in roadcut (32°29.9'N, 110°40.7'W; Mt. Bigelow quad., Pima Co., AZ) nearly surrounded by Neogene alluvial deposits and probably a mid-Tertiary dike intruding uppermost Cretaceous and/or lowermost Paleogene American Flag Formation (Janecke, 1986). *Analytical data:* K = 6.734, 6.799, 6.849%; ^{40}Ar = 325.2, 328.0, 324.1 pm/g; atm. Ar = 38.4, 38.3, 38.7%.

(biotite) 27.4 ± 0.7 Ma

10. *UAKA 78-62* K-Ar
Flow-banded rhyolite (32°28.05'N, 110°19.24'W; Redington quad., Graham Co., AZ) in Galiuro Volcanics exposed at bottom of Jackson Canyon W of trail from Jackson Cabin to Redfield Canyon in Galiuro Mountains (fig. 4, col. VIII). *Analytical data:* K = 4.074, 4.102, 4.096%; ^{40}Ar = 174.2, 174.5 pm/g; atm. Ar = 6.6, 6.9%.

(feldspar) 24.4 ± 0.5 Ma

11. *UAKA 78-60* K-Ar
Rhyolite dike (32°24.54'N, 110°16.12'W; Redington quad., Graham Co., AZ) cutting Galiuro Volcanics near road from Pride Ranch to Jackson Cabin in Galiuro Mountains. *Analytical data:* K = 4.851, 4.842, 4.786%; ^{40}Ar = 211.2, 211.9, 210.4 pm/g; atm. Ar = 9.2, 9.8, 9.1%.

(feldspar) 25.1 ± 0.5 Ma

12. *UAKA 83-75* K-Ar
Basaltic andesite clast (32°21.15'N,110°26.08'W; Soza Canyon quad., Cochise Co., AZ) from sedimentary megabreccia intercalated within Soza Canyon facies of San Manuel Formation, but composed of debris reworked from Galiuro Volcanics overlying Mineta Formation nearby (footnote 25, fig. 4, col. IX); megabreccia horizon is stratigraphically about 100 m below concordant contact with overlying Quiburis Formation. *Analytical data:* K = 1.908, 1.906, 1.912, 1.913, 1.914, 1.910, 1.900, 1.912%; ^{40}Ar = 85.70, 85.16, 85.56, 85.52, 84.46, 83.89, 83.93, 84.09, 85.06, 83.74, 84.27, 84.08, 84.46 pm/g; atm. Ar = 13.0, 12.6, 12.9, 12.4, 13.5, 14.8, 14.4, 14.2, 13.6, 16.1, 13.9, 14.6, 15.0%.

(groundmass feldspar) 25.5 ± 0.6 Ma

13. *UAKA 78-33* K-Ar
Rhyolitic ash-flow tuff (32°17.1'N, 110°27.28'W; Redington quad., Pima Co., AZ) resting depositionally beneath type Mineta Formation; rock is altered and age is suspect from known stratigraphic relations (fig.

4, col. IX). *Analytical data:* K = 3.736, 3.734, 3.721%; ^{40}Ar = 163.9, 163.8, 162.7 pm/g; atm. Ar = 40.6, 41.2, 38.8% (#693 of Reynolds and others, 1986; after Scarborough and Wilt, 1979).

(groundmass feldspar) 25.1 ± 0.6 Ma

14. *UAKA 78-41* K-Ar
Basaltic andesite lava of basal Galiuro Volcanics (32°17.07′N, 110°16.40′W; Redington quad., Cochise Co., AZ) intercalated locally with uppermost Mineta Formation (Grover, 1982) in Teran Basin area (fig. 4, col. VIII). *Analytical data:* K = 1.985, 1.971, 1.969%; ^{40}Ar = 94.01, 94.28, 94.25 pm/g; atm. Ar = 15.5, 15.9, 16.3% (#789 of Reynolds and others, 1986; after Scarborough and Wilt, 1979).

(groundmass feldspar) 27.3 ± 0.6 Ma

15. *UAKA 87-182* K-Ar
Ash-flow tuff (31°59.75′N, 110°37′W; The Narrows quad., Pima Co., AZ) resting depositionally below Pantano Formation (Balcer, 1984) in roadcut along I-10 Freeway near Davidson Canyon W of Cienega Gap (fig. 4, col. X). *Analytical data:* K = 7.284, 7.256, 7.289, 7.207%; ^{40}Ar = 439.3, 436.7, 434.8, 437.8 pm/g; atm. Ar = 12.0, 12.7, 12.8, 12.7%. Damon and Bikerman (1964) reported concordant K-Ar ages, for samples collected nearby from the same horizon, of 33.6 ± 2.7 and 37.6 ± 1.7 on biotite and sanidine, respectively (#909 and #936 of Reynolds and others, 1986).

(biotite) 34.4 ± 0.8 Ma

16. *UAKA 87-146* K-Ar
Air-fall tuff in Hell Hole Canyon of Deer Creek, tributary of Aravaipa Creek (32°54.5′N, 110°28′W; Booger Canyon quad., Pinal Co., AZ) within relatively flat-lying Hell Hole Conglomerate (fig. 4, col. VII), which fills a basin bounded by buttress unconformities with flat-lying Galiuro Volcanics to the west and tilted Horse Mountain Volcanics to the east. *Analytical data:* K = 5.867, 5.792, 5.884, 5.867, 5.863%; ^{40}Ar = 196.8, 196.9, 195.8, 193.9 pm/g; atm. Ar = 40.3, 40.8, 41.1, 43.3%.

(biotite) 19.2 ± 0.5 Ma

17. *UAKA 83-166* fission-track
Silicic air-fall tuff along Smelter Wash (32°39.47′N., 110°39.16′W; Mammoth quad., Pinal Co., AZ) intercalated as lensoid body within San Manuel Formation. *Analytical data:* apatite, DF-5114, 11 grains: $P_s = 0.12 \times 10^6$ tracks/cm^2 (120 tracks counted); $P_i = 2.66 \times 10^6$ tracks/cm^2 (1376 tracks counted); neutron dose = 7.10×10^{15} N/cm; uranium = 14.9 ppm; counted by M. Shafiqullah.

(apatite) 18.5 ± 3.6 Ma

18. *UAKA 76-127* K-Ar
Trachyte (32°38.9′N, 111°11.2′W; Tortolita Mountains quad., Pinal Co., AZ) of porphyritic flow from small butte near The Huerfano butte (table 2, E). *Analytical data:* K = 6.432, 6.356, 6.392%; ^{40}Ar = 281.8, 280.5, 282.4 pm/g; atm. Ar = 12.5, 12.8, 12.6%.

(biotite) 25.1 ± 0.5 Ma

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