SUMMARY OF TERTIARY STRATIGRAPHIC AND STRUCTURAL RELATIONSHIPS, CAMP GRANT WASH – ANTELOPE PEAK AREA, PINAL COUNTY, ARIZONA

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Introduction

The accompanying geologic map (scale 1:24,000) displays the structural and stratigraphic relationships of faulted homoclines of largely undated mid-Tertiary strata exposed over an area of ~250 km² in the drainages of Camp Grant, Putnam, Dodson, and James Washes in uplands between the Santa Catalina and Tortilla Mountains west of the San Pedro trough. The dominantly homoclinal mid-Tertiary strata dip generally east-northeast, and are cut by normal faults dipping generally west-southwest. Previous maps of various parts of the study area at comparable scale (Krieger, 1968, 1974a, 1974b, 1974c; Hansen, 1983) were prepared without information now available about regional stratigraphic relationships (Dickinson, 1991). Most key geologic features were plotted correctly during previous mapping at smaller scale (Dickinson, 1987, sheets 3, 4, 6; 1988; 1991, figs. 1, 46; 1992), but the detailed placement of contacts and structures on the accompanying geologic map supersedes past mapping. In particular, an exposure of the Cloudburst Formation is delineated between James and Polecat Washes near the northern end of the map area, the position of the base of the Quiburis Formation along the western flank of the San Pedro trough is revised (from Dickinson, 1998, sheet 2) in the vicinity of Dodson and James Washes to the north of Elgin Wash, and transverse east-west faults (Cactus Hill and Putnam Wash faults) are mapped more completely and accurately than before.

Tertiary conglomeratic units are composed of clasts derived from varied bedrock exposed in uplands immediately surrounding the map area, but neither clast assemblages nor paleocurrent trends (rude clast imbrications) were recorded systematically during the present study. The map now provides a fresh basis for analysis of provenance relations and sediment dispersal within the area. In general, the most abundant clast types are Precambrian granite or schist. Subordinate clast types, which are locally dominant at selected horizons, include Precambrian diabase, quartzite from Precambrian and/or Paleozoic source rocks, Paleozoic limestone, and mid-Tertiary volcanic rocks reworked from the volcanic lower member of the Cloudburst Formation exposed in the Black Hills southeast of the study area and the Black Mountains southwest of the study area.
Access

Access is provided by (a) Freeman Road along James Wash near the north edge of the map area, (b) 4WD tracks up Putnam and Camp Grant Washes from the San Pedro River opposite the mouth of Aravaipa Creek and up Dodson Wash from Freeman Road, (c) 4WD tracks into Camp Grant Wash via both Cronley and Capgage Washes from the San Pedro west-side road north of Mammoth, (d) a pipeline road into Camp Grant Wash from the head of Tucson Wash southwest of Mammoth, and (e) 4WD tracks down Palmer and Bloodsucker Washes from Star Flat on the Willow Springs Road north of Oracle Junction. Both mapped and unmapped ranch roads branching from major access routes provide further detailed access within the map area, with few localities more than a mile or two from vehicle access. Elevations range from a minimum of 2463 feet at the confluence of Putnam and Camp Grant Washes at the eastern edge of the map area to a maximum of 4547 feet at the crest of Antelope Peak between Dodson and James Washes.

Overall Geomorphology

Bold ridges along the eastern fringe of the map area are underlain by pre-Tertiary bedrock separating exposures of tilted mid-Tertiary strata and overlying undeformed gravels in the interior of study area from the San Pedro trough, where counterparts of the deformed mid-Tertiary strata are either onlapped or buried by post-mid-Miocene basin fill of the Quiburis Formation (Dickinson, 1991, 1998). Morphologically, the interior of the map area is largely a dissected subregional pediment surface, probably of Pliocene to Pleistocene age, above which the inselberg of Antelope Peak rises as the only major topographic prominence. Modern trunk and tributary drainages of Camp Grant, Putnam, and Dodson Washes are deeply incised into the pedimented surface, with pediment remnants forming mesa-like tablelands or accordant ridge crests flanked by cliffed outcrops on canyon walls. The incised drainages typically display flat floors underlain by modern sandy alluvium. Higher topography to the west is underlain by less deeply dissected post-mid-Tertiary gravels mantling the flank of the Black Mountains but also truncated upward by the pediment surface. The gravel blanket merges southward with the less dissected gravel cap of Falcon Valley or Divide west of Oracle. Neither wash-floor alluvium nor stream and pediment terraces were mapped separately from underlying pre-Quaternary units during this study.

General Stratigraphy

Tertiary strata exposed within the Camp Grant Wash–Antelope Peak area are assigned to three formations: (1) Cloudburst Formation of inferred Late Oligocene age, (2) San Manuel Formation of inferred Early Miocene age, and (3) gravels of Camp Grant Wash (Dickinson, 1993, 1994) of inferred post-mid-Miocene (probably Pliocene) age. No fossil or radiometric ages are available from any of the three sedimentary successions within the map area. A volcanic unit of restricted extent erupted near the Oligocene-Miocene time boundary locally underlies onlapping strata of the San Manuel Formation, and is inferred from known regional relations to postdate deposition of the Cloudburst
Formation (Dickinson, 1991). On the northeast, basal strata of the post-mid-Miocene Quiburis Formation, basin fill of the San Pedro trough to the east, unconformably overlap more steeply dipping strata of the San Manuel Formation along the edge of the map area (see also Dickinson, 1998, sheet 2).

**Cloudburst Formation.** Conglomeratic redbeds of the map area are generally correlative with the sedimentary upper member of the Cloudburst Formation (Dickinson, 1991, Table 7) in the Black Hills to the southeast (Dickinson, 1991, Figs. 36, 49; Dickinson, 1993) and at Star Flat to the southwest (Dickinson, 1991, Figs. 36, 46; Dickinson, 1994), and/or with the Hackberry Wash facies of the Cloudburst Formation (Dickinson, 1991, Table 7; Dickinson, 1996) in the Tortilla Mountains along tectonic strike to the northwest (Dickinson, 1991, Figs. 35, 40). The principal outcrops form the lowest exposed stratigraphic horizons of a northwest-striking homocline of mid-Tertiary strata, dipping to the northeast and striking across Camp Grant Wash and the interfluve to the north that forms a spur of rugged uplands between Camp Grant and Putnam Washes. Additional outcrops occur within a local half-graben exhumed from beneath San Manuel Formation near the north edge of the map area between James and Polecot Washes. The principal Cloudburst exposures along Camp Grant and Putnam Washes are bounded on the northeast by the Camp Grant fault or depositionally overlying strata of the San Manuel Formation, and on the southwest by the Cowhead Well fault.

The Cloudburst strata were assigned by Krieger (1974a, 1974c) to a unit of “nongranitic red alluvial deposits” mapped within the San Manuel Formation, but the distinct reddish coloration, unobserved either locally or elsewhere within either the San Manuel Formation or younger units, supports correlation with the older Cloudburst Formation, within which a characteristic red coloration is everywhere ubiquitous.

**San Manuel Formation.** Well indurated conglomeratic to sandy strata overlying the Cloudburst Formation unconformably, or else resting depositionally on pre-Tertiary basement where the Cloudburst Formation is absent, are correlated with lithologically indistinguishable strata of the San Manuel Formation (Dickinson, 1991, Table 7), as widely exposed within the surrounding region. San Manuel strata occupy comparable stratigraphic intervals throughout the San Pedro trough and crop out in several nearby areas (Dickinson, 1991, Figs. 35, 36, 40, 42; Dickinson, 1996), including the type area in the Black Hills to the southeast (Dickinson, 1993) and the Star Flat–Willow Springs area on the flank of the Black Mountains to the southwest (Dickinson, 1994). Tawny to buff or gray hues contrast with the redbed character of the underlying Cloudburst Formation. San Manuel exposures occur as two faulted homoclines lying east and west of the Cowhead Well fault. An especially well bedded to laminated interval of sandstone and conglomeratic sandstone forming medial stratigraphic horizons within San Manuel Formation on the downthrown side of the Cowhead Well fault is termed the Beehive Well member (after Beehive Well in Putnam Wash). Paleocurrents in the lower San Manuel Formation below the Beehive Well member reflect derivation of alluvial fans and braidplains from the west and southwest in the tilted Black Mountain block forming the hanging-wall flank of a compound half-graben system, whereas paleocurrents in the upper San Manuel Formation
above the Beehive Well member reflect derivation of alluvial fans and braidplains from the footwall block to the east and northeast. The comparatively well bedded Beehive Well member probably represents a transitional phase of basin-floor deposition reflecting longitudinal sediment transport within the half-graben system (Dickinson, 1991, p. 79), but cannot be identified northward from Putnam Wash.

Strata of the San Manuel Formation were generally mapped as such by Krieger (1974a, 1974c), although the distinction between San Manuel Formation and overlying younger strata mapped here as gravels of Camp Grant Wash was not everywhere clearcut. Within the drainages of Elgin, Dodson, and James Washes in the northeastern part of the map area, parts of the San Manuel exposures were mapped by Krieger (1974a,c) as “Big Dome Formation”, which is no longer regarded as a valid stratigraphic entity (Dickinson, 1991, Table 7, p. 73 & 76).

In one small area southeast of Yellowjacket Well, olivine-bearing mafic lava lying depositionally beneath sedimentary strata of the San Manuel Formation, and resting in turn directly upon Precambrian basement, has yielded a K-Ar age of 22.1 ± 0.5 Ma (Dickinson and Shafiqullah, 1989), corresponding to earliest Miocene time (Shackleton et al., 2000). Petrologically similar mafic lavas of comparable age (21-23 Ma) occur just beneath the San Manuel Formation or its equivalents to the southwest in the Guild Wash allochthon west of the Tortolita Mountains and within the Galiuro Mountains east of the San Pedro trough (Dickinson, 1991, p. 65).

Camp Grant gravels. Unconsolidated to semi-consolidated gravelly and locally sandy deposits, assigned here to the gravels of Camp Grant Wash (Dickinson, 1993, 1994), rest unconformably on pre-Tertiary bedrock or upon older Tertiary units, display largely initial dips, and underlie extensive benchlands in the headwater reaches of Camp Grant Wash and its tributaries. Most exposures are coarse gravelly deposits of alluvial-fan affinity, but a central facies of arkosic sandstone exposed only in cutbanks along upper Camp Grant Wash probably represents fluvial deposits of an ancestral Camp Grant Wash flanked to either side by piedmonts sloping inward from the Black Hills to the east and the Black Mountains to the west. Deposition occurred after tilting of pre-mid-Miocene units but before pedimentation and subsequent deep dissection of the landscape. Alluvium and terrace or pediment gravels deposited in sites congruent with modern topography are distinctly younger than the Camp Grant gravels, which are possibly correlative with upper horizons of the Quiburis Formation within the San Pedro trough to the east but may be entirely younger.

There is at present no means of comparing the exact age of post-mid-Miocene basin fill in the San Pedro trough with post-mid-Miocene basinal deposits along the axis of the Camp Grant depositional system within its subsidiary structural trough. Camp Grant gravels are locally offset by the Cowhead Tank fault delineating the western flank of the Antelope Peak tiltblock, but overlap all other faults within the map area. Although they were not reliably distinguished from the San Manuel Formation in all areas of mutual
exposure, the gravels of Camp Grant Wash were mapped in many places as “sand and gravel” (of presumed Quaternary age) by Krieger (1974c).

**Principal Structures**

Three major NNW-trending faults offset homoclines of mid-Tertiary strata. From east to west and oldest to youngest, they include: (1) Camp Grant fault [although Hansen (1983) showed that the Camp Grant fault is the same structure as the San Manuel fault of the Black Hills farther south, the separate nomenclature of Krieger (1974c) is retained here because the two exposed fault traces are nowhere contiguous]; (2) Cowhead Well fault [northern segment miscorrelated with the Camp Grant fault by Krieger, 1974a, 1974c], and (3) Cowhead Tank fault [new name]. All are west-dipping normal faults, but the oldest (Camp Grant fault) is consistently low-angle (~30°), the youngest (Cowhead Tank fault) is consistently steep (though exposures are inadequate to establish an accurate dip), and the trace of the third (Cowhead Well fault, intermediate in age) is suggestive of variable intermediate dips, probably in the range of 40°-70°. The correlation of fault dip with age suggests either that low-angle normal faulting within the area was succeeded in time by high-angle normal faulting, or that older structures were progressively tilted as extensional deformation proceeded. An even older subhorizontal detachment surface (Cloudburst-Star Flat fault) of normal-sense displacement is probably present at depth beneath at least the southern part of the map area.

**Cloudburst–Star Flat faults.** Both east and west of the southern part of the map area, steeply dipping homoclines (ENE dip) of Cloudburst Formation are truncated downdip by tilted, gently backdipping (subhorizontal ENE dip), low-angle detachment-style normal faults, the Cloudburst fault of the Black Hills near Mammoth (Dickinson, 1993) and the Star Flat fault near the Willow Springs Ranch on the east flank of the Black Mountains (Dickinson, 1994). By analogy, a correlative or related subhorizontal fault surface is inferred at depth beneath the sequence of Cloudburst Formation exposed along Camp Grant Wash and bordering uplands. Movement on the buried subhorizontal fault probably occurred during Late Oligocene time prior to deposition of the San Manuel Formation.

**Camp Grant fault.** Thick successions of Cloudburst Formation and overlying (unconformably to disconformably) San Manuel Formation are backtilted (ENE dips) against the gently dipping (WSW dips) Camp Grant fault (dip <30°). Megabreccia bodies that are interstratified within the Cloudburst Formation near the fault (along the floor of “Big Red Canyon”), reflecting the presence of syndepositional fault scarps, suggest that displacement began during waning phases of Cloudburst deposition. Coarsening of the San Manuel Formation toward the fault in areas north of Putnam Wash implies continued syndepositional displacement during Early Miocene time. Both to the north and to the south of the gorge of Putnam Wash, basement uplands are exposed in the footwall. Deformation associated with displacements along the Camp Grant fault controlled development of a half-graben, now composite because of later disruption by younger faulting, to which exposures of the San Manuel Formation within the map area are
The Camp Grant fault is locally overlapped by the post-mid-Miocene Quiburis Formation of the San Pedro trough (in Elgin Wash at the northeast edge of the map area) and by the Pliocene (?) gravels of Camp Grant Wash (at the southeast edge of the map area near Hidden Tank and Hidden Well). The overlap of Camp Grant gravels is a buttress unconformity onlapping a residual fault scarp.

**Cowhead Well Fault.** Because the more steeply dipping Cowhead Well fault offsets internal facies of the San Manuel Formation but is overlapped by the gravels of Camp Grant Wash, intra-Miocene displacement is inferred, after deposition of at least part of the San Manuel Formation but before deposition of the Camp Grant gravels. Continued syntectonic deposition of the San Manuel Formation is implied by the common presence of megabreccia bodies within exposures of San Manuel Formation adjacent to the fault in the southernmost part of the map area. East of upper Camp Grant Wash and near Dodson and James Washes, basement tiltblocks are exposed in the footwall, but elsewhere the fault is bordered on both sides by tilted mid-Tertiary strata. The trace is well marked where the fault forms a contact between Cloudburst and San Manuel strata, but its position in poorly exposed uplands north of Putnam Wash is indicated only by contrasts in the dips of San Manuel strata across the structure. In Putnam Wash, the general position of the crest of a buried basement tiltblock along the upthrown side of the Cowhead Well fault was detected gravimetrically by Hansen (1983). Because the Cowhead Well fault offsets the Camp Grant fault, their relative ages are not in doubt, quite apart from differing stratigraphic relationships across the two structures.

**Cowhead Tank fault.** The steeply dipping Cowhead Tank fault (~75°?) locally offsets the gravels of Camp Grant Wash, as well as older rock units, but does not break pedimented topographic surfaces, and is therefore inferred to be a Pliocene structure. The prominent inselberg of Antelope Peak north of Putnam Wash occupies a tiltblock in the footwall of the Cowhead Tank fault. A more subdued basement exposure is present in the footwall south of Putnam Wash (crossing Bloodsucker Wash), but an isolated outcrop of disrupted plutonic and volcanic rocks mapped by Krieger (1974c) as exposed basement still farther to the southeast, between Bloodsucker and Palmer Washes, is actually debris-avalanche megabreccia intercalated within the San Manuel Formation (see annotation on accompanying map). Southward overlap of the Cowhead Tank fault trace by Camp Grant gravels between Bloodsucker and Palmer Washes indicates both that movement on the Cowhead Tank fault was syndepositional and that displacement decreased toward the south.

**Transverse Faults.** Two transverse east-west faults (Putnam Wash and Cactus Hill faults), with uncertain but steep dips, offset homoclines of mid-Tertiary strata along selected reaches of Putnam and James Washes. Stratigraphic separations indicate either that the structures are sinistral (left-lateral) strike-slip faults, or that the ground between them is horst-like, with displacement of basement down to the north across the Cactus Hill fault on the north and down to the south across the Putnam Wash fault on the south. The latter interpretation is preferred here, because neither fault can be traced far to the east or west, and largely vertical movement across the faults permits the hypothesis of scissors.
motion, with displacements dying out or varying in sense laterally. Along the Putnam Wash fault, displacement was apparently down to the south on the east, but down to the north on the west. The alternate hypothesis of strike slip is therefore attractive but difficult to reconcile with key relations to the east and west of the well defined segment of the fault trace.

The Putnam Wash fault offsets the Camp Grant fault and the homocline of tilted mid-Tertiary strata lying to the west, where San Manuel Formation is juxtaposed against Cloudburst Formation across the fault, but cannot be traced very far through bedrock exposures to the east. Nor could it be traced westward past a poorly exposed juncture with the Cowhead Well fault, which apparently truncates the Putnam Wash fault. It is possible, however, that an offset continuation of the Putnam Wash fault may be present west of the Cowhead Well fault, because the northward facies limit of the Beehive Well facies of the San Manuel Formation lies approximately along trend with the Putnam Wash fault. If an ancestral Putnam Wash fault continues westward through the poorly exposed area west of the Cowhead Well fault, its position may conceivably have influenced the southern extent of bedrock exposures in the Antelope Peak tiltblock adjacent to the Cowhead Tank fault, although no evidence of faulting was detected where exposed horizons of the San Manuel Formation onlap the southern tip of the tiltblock.

Since the Putnam Wash fault is apparently truncated by the Cowhead Well Fault, it may be of the same age, reflecting disruption of the footwall of the Cowhead Well fault relative to the hanging wall during faulting. If the Putnam Wash fault is older, with a cryptic extension to the west of the Cowhead Well fault, it may nevertheless have been reactivated during movement along the Cowhead Well fault. A broadly east-west belt of variably anomalous dips in the San Manuel Formation on both sides of the Cowhead Well fault north of Putnam Wash may reflect heterogeneous deformation of both the hanging wall and footwall in a geometric pattern related somehow to the presence of an ancestral Putnam Wash fault not far to the south. Somewhat analogous east-west dips in the San Manuel Formation southwest of Tunnel Ranch near the southern edge of the map area may reflect proximity to yet another transverse structure buried beneath nearby Camp Grant gravels.

The Cactus Hill fault, aligned along a segment of James Wash farther north, makes a juncture with the Cowhead Well fault beneath the broad valley of James Wash where the nature of the fault interaction is obscure beneath a mantle of stream terrace deposits. The Cactus Hill fault appears, however, to be confined to the footwall of the Cowhead Well fault. To the east, the base of the post-mid-Miocene Quiburis Formation is not visibly offset along the projected trend of the Cactus Hill fault, but broad stream terraces mask the course of the structure as it nears Quiburis exposures.

From their apparent relationships to Tertiary structure and stratigraphy, slip on the Putnam Wash and Cactus Hill faults is inferred to have occurred during mid-Miocene time, after deposition of most or all of the San Manuel Formation but before post-mid-Miocene deposition of the Quiburis Formation and the gravels of Camp Grant Wash.
References Cited


MAP LEGEND

Linework: contacts and faults solid lines where accurately located and dashed where approximate (one segment of Camp Grant fault dotted where concealed)

lightweight: depositional or intrusive contacts undifferentiated

heavyweight: normal faults (hachures on hanging wall of low-angle Camp Grant normal fault; balls on hanging walls of steep normal faults)

Symbols: [Quaternary cover unmapped; pre-Tertiary rocks not depicted in detail]

A. Post-mid-Miocene stratal cap

Tcg Camp Grant gravels (or gravels of Camp Grant Wash)

Tq Quiburis Formation (basin fill of San Pedro trough)

B. Tilted mid-Tertiary strata

Tsm San Manuel Formation (Tbw: well bedded Beehive Well facies)

Tvy olivine-bearing basaltic andesite lava southeast of Yellowjacket Well

Tcb Cloudburst Formation (only sedimentary member present in map area)

C. Pre-Tertiary substratum [both Xpi & Yor intruded locally by Precambrian diabase]

Pzs Paleozoic sedimentary strata (exposed locally in Elgin Wash only)

Yap Middle Proterozoic Apache Group (exposed near north edge of map area)

Yor Middle Proterozoic Oracle-Ruin granite suite (of Dickinson, 1991)

Xpi Lower Proterozoic Pinal Schist