GEOLOGY OF THE KITTY JOE CANYON AREA, MAZATZAL MOUNTAINS, ARIZONA

prepared for
Arizona Department of Transportation

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THIS STUDY AND ITS PRODUCTS

This report and accompanying maps are the final products in fulfillment of a contract between the U.S. Geological Survey (USGS) and the Arizona Department of Transportation (ADOT) for the USGS to study and report on the geology of the Kitty Joe Canyon area, where a new highway is to be constructed, and on four bridge sites. This work was begun 16 December 1994.

An approximately 2 by 8 mile strip was mapped at 1:12,000 scale between Sunflower and Slate Creek (Segment F, Sunflower to mile post 226, of State Road 87, the Mesa to Payson Highway). A preliminary version of this regional map was submitted to ADOT 2 March 1995.

Detailed maps (1:1,200 scale) and cross-sections of the four bridge sites were completed and submitted as follows: Cottonwood bridge site, 26 April 1995; Whiskey Springs bridge site, 19 May 1995; upper Kitty Joe bridge site, 31 May 1995; lower Kitty Joe bridge site, 30 June 1995.

A final colored version of the regional map, including Correlation of Map Units, Description of Map Units, and Map Symbols, was submitted in late August and early September, 1995. This map in this report is referred to as the regional map, or more commonly, simply the geologic map or the map. The present submittal contains, in addition to this text and accompanying figures, four additional uncolored copies of the regional map with accompanying correlations and descriptions of maps units and map symbols. One of the four map copies shows the locations of the bridge site maps and also shows 5,000-foot intervals (2500, 2550, etc.), according to ADOT's measuring convention, along the highway centerline.

The 1:12,000-scale base for the regional map was prepared by the U.S. Geological Survey from scale-stable negatives of the Reno Pass and Boulder Mountain 7-1/2' quadrangles. The 1:1,200-scale base maps (5' contour intervals combined with orthophotography) for the bridge sites were prepared by the Photogrammetry and Mapping Division of ADOT.

INTRODUCTION TO THE GEOLOGY

Segment F, the planned highway between Sunflower and Slate Creek in the Mazatzal Mountains, passes largely along the eastern margin of a Tertiary basin-fill sequence. This basin-fill sequence rests on Early Proterozoic orogenic rocks and laps out eastward against Early Proterozoic rocks that underlie Mt. Ord, which also existed as a high area during the time of the deposition of these Tertiary rocks. The basin into which this Tertiary sequence was deposited is here named the Kitty Joe basin. The Tertiary units deposited into that basin are informally referred to here as the Kitty Joe sequence. This report emphasizes the units of the Kitty Joe sequence, and unconformably overlying Tertiary volcanic units, here called upper sequence, because these are the rocks into which cuts will be made and on which almost the entire highway will be constructed.

The Early Proterozoic rocks of the northern part of the study area, in and near Slate Creek, have been extensively studied previously. Early Proterozoic rocks on the western and southern slopes of Mt. Ord, primarily metamorphosed mafic volcanic rocks and red leucogranite, have not been previously studied and were given only cursory examination in this study. Because the highway will rest on Proterozoic rocks in only two tiny segments, little attention is given to the Proterozoic basement in this report.

Superficial material of many Quaternary units constitutes most of the actual surface rock in the Kitty Joe region. This includes both mapped units as portrayed on the geologic map and a widespread, intermittent veneer that was not mapped. Generally these superficial materials are only a few feet to a few tens of feet thick, but locally reach thicknesses of several hundred feet. The landslide deposits are in the latter category. Older valley fill alluvium in the Sunflower area is likely many tens of feet thick. Only locally do the Quaternary rocks have sufficient thickness to be a major consideration in the highway engineering and actual road construction.

Tertiary tectonics have imparted an important structural character on the Kitty Joe sequence. A few early north-south faults are least important to the highway construction. Northwest-southeast faults are numerous and define an assymetric graben in the southern part of the area and perhaps extending into the northern part. Strata generally dip gently to the southwest toward a major fault, the Sunflower fault, which forms the southwest margin of the graben. A joint system, parallel to and genetically related to the graben-forming faults exists throughout the study area.

By its nature, this study afforded little time for topical study or for quantification. Consequently, the report contains considerable

generalization and many values it contains of size, thickness, and percentage are simply estimates. The rock types may not all be properly named petrographically; practical field names are used. For example, biotite basalt, may be properly a biotite lamprophyre or trachyandesite. Extensive refinement is in order in any future study of the area.

EARLY PROTEROZOIC ROCKS

The Precambrian rocks in the northern part of the study area are part of a complex of metavolcanic and metasedimentary rocks that received attention many years ago (Ransome, 1915; Lausen, 1926; Wilson, 1941; Faick, 1958) because of the presence of mercury deposits. The nearby mercury mines (e.g. Ord mine in Alder Creek and Sunflower mine in upper Sycamore Creek), long since closed, are part of a cluster of mines in the Mazatzal Mountains mercury district. Although this district is Arizona's best mercury producer by far, its production was minor compared to major mercury districts elsewhere in the U.S. (Bailey, 1969; Wrucke and others, 1983).

The Early Proterozoic units in the Slate Creek area were named Red Rock rhyolite and Alder series by Wilson (1939) and are now assigned to the Red Rock Group and to the Alder Group of the Tonto Basin Supergroup (Wrucke and Conway, 1987; Conway and Silver, 1989).

Recent studies of these Proterozoic rocks have focused on their stratigraphy and structure. Ludwig (1974) subdivided and named units within the Alder Group and determined that they were stratigraphically beneath the Red Rock Group in a northeast-trending syncline that he called the Red Rock syncline. The axial trace of this syncline is just off the northern margin of the study area.

Roller's (1987) detailed structural study in the Slate Creek area indicated more complexity in the Alder Group than recognized by Ludwig. She defined a broad zone containing shear zones in Slate Creek that she called the Slate Creek movement zone. Her results cast doubt on the validity of Ludwig's Alder Group stratigraphy in the southeastern limb of the Red Rock syncline.

The current study provides a little additional structural data for the Alder Group rocks in the Cottonwood Basin tributary to Slate Creek, but contributes nothing to the current overall stratigraphic/structural problem. For this study, all units beneath Ludwig's (1974) Telephone Canyon member are lumped as 'schistose rocks, undivided' (unit Xasu).

Large areas of Early Proterozoic mafic volcanic rock (Xmv), metamorphosed in the greenschist facies, were mapped in this study on the eastern margin of Kitty Joe basin. These are continuous with mafic volcanic rocks underlying large areas at and around Mt. Ord (Ludwig,

1974; reconnaissance mapping by the author). Masses of intrusive rocks, notably porphyritic granodiorite to quartz diorite are associated with the mafic volcanic rocks. The relation between the mafic metavolcanics and the Alder Group rocks in the Slate Creek area is not known. These mafic rocks may belong to lower parts of the Alder Group as do mafic volcanic rocks in the northwestern limb of the Red Rock syncline (Wrucke and Conway, 1987) or they may be an older basement unconformably beneath the Alder Group as proposed by Anderson (1989).

Southeastern parts of the map area, in Ram Valley and on southern slopes of Mt. Ord are widely underlain by red, leucocratic, medium- to locally fine-grained granite (Xgr, granite of Ram Valley). This granite, in which mafic minerals are largely altered to hematite, is highly reminisent of widespread red granite in Tonto Basin, northern Mazatzal Mountains, and the northern New River Mountains region. These granites belong to the Diamond Rim Intrusive Suite and have been dated in places at ~1700 Ma (Conway and Silver, 1989; Wrucke and Conway, 1987). As do these red granites elsewhere, the granite of Ram Valley contains local shear/mylonite zones trending north-northeast to northeast. These are likely deformational zones formed during the Mazatzal orogeny.

The granite of Sunflower (Xgs) is much coarser, and far less oxidized than granite of Ram Valley. Biotite is well preserved in this tan granite. It appears in the limited outcrops examined to be entirely without tectonic fabric. This was also the observation of Silver (1965) who suggested the granite of Sunflower and a granite near Young, Arizona (Conway, 1976) were post-tectonic granites. He dated these granites at 1660-1650 Ma (~1640-1630 Ma, by revised decay constant) thus placing a lower limit on the time of the Mazatzal Orogeny (Silver, 1967). Silver's dated sample of the granite of Sunflower comes from a roadcut likely in the southern part of the map area or within a mile or two south of the map area.

The current brief study of the Early Proterozoic rocks in the Kitty Joe Canyon area, as well as numerous field and geochronologic studies elsewhere in the southwestern United States over the past two decades, continue to support the concepts and the chronology put forth by L. T. Silver in the early 1960's.

TERTIARY ROCKS

Conglomerate

A small outcrop of presumably Tertiary conglomerate (Tc) crops out in the extreme southwestern part of the map area between Diamond Mountain and Highway 87. More extensive outcrops lie due south of this occurrence one-fourth to one-third mile south of the map margin; they lie

100-200 feet west of the old abandoned beeline road at the southernmost margin of Section 19.

This conglomerate is distinct from any of the Tertiary gravel units in the map area. It is rather strongly lithified and forms bold outcrops including small cliffs in the area south of the map. Secondly, it contains numerous beds consisting almost entirely of K-feldspar crystals up to 3 cm. I failed to make notes and cannot recall the overall suite of clasts in this conglomerate. South of the map area the conglomerate is nearly horizontal, possibly dipping gently to the south.

I suspect this conglomerate is older than the Kitty Joe sequence because of its well-cemented character and distinct lithology, although this is admittedly poor evidence. It could feasibly be interbedded with the regional arkosic gravel unit, Tga.

Kitty Joe Sequence

The Kitty Joe sequence consists of poorly consolidated gravels, breccias, and interbedded volcanic rocks that filled the ancient Kitty Joe basin probably about 20-25 million years ago. In a slight oversimplification, the Kitty Joe sequence consists of arkosic gravel (Tga) and all its various interbedded units (see large box with tongues in central part of Correlation of Map Units). However, I also include in the Kitty Joe sequence the coarse fanglomerate unit (Tgm) which may entirely underly the arkosic gravel, but could feasibly be interbedded with lower parts. I also tentatively include the olivine basalt flows (Tbo) in the central part of the area. Although these flows appear to be entirely above the arkosic gravel, they are of limited areal extent, like many units in the Kitty Joe sequence and unlike the overlying felsic tuff and basalt. Moreover, these flows are lithologically similar to a flow within the Kitty Joe sequence below the biotite basalt.

Above the Kitty Joe sequence, an unconformity was identified beneath the upper basalts (unit Tbu). Likely also there is an unconformity (or nonconformity) beneath the felsic tuff, although it was not recognized in the field. This is suspected because the felsic tuff is about 5.3 Ma whereas biotite basalt (Tbb) and thus the arkosic gravel are likely on the order of 20-25 Ma (see below). Whereas the unconformable relation between the upper basalt (Tbu) and the cinders and gravel unit (Tcg) may represent a short period during which a soft volcaniclastic edifice was eroded, the period between the deposition of the Kitty Joe sequence and the felsic tuff may have been substantial - on the order of 15-20 Ma. Units above this this hypothetical unconformity are informally included in the upper sequence.

There are three independant arguments for an early Miocene (to possibly late Oligocene) age of the Kitty Joe sequence. The first is that mafic volcanic rocks similar to the unusual biotite basalt (Tbb and Tbx) elsewhere in the Transition Zone of Arizona have been dated at 27-21 Ma (Sullivan Buttes) and 22 Ma (Turkey Canyon). These rocks, including the xenolith-bearing biotite basalt of the study area, are considered latites by Nealey and Sheridan (1989). These authors and others suggest that such 'latites' constitute a singular regional magmatic event in the Transition zone in late Oligocene to early Miocene time.

The second argument derives from consideration of the provenance of the Apache Group clasts in the arkosic gravel (Tga). There are abundant clasts of the Dripping Spring Quartzite and Troy Quartzite of the Middle Proterozoic Apache Group in the arkosic gravel of the Ram Canyon and Kitty Joe Canyon areas. The Apache group and Troy Quartzite (Shride, 1967; Wrucke, 1989) crop out only to the northeast, east, and southeast of the study area - across the divide of the Mazatzal Mountains and across Tonto Basin (Tonto Creek) or the Salt River! Only tiny exposures of the Apache Group, at lower elevations near Roosevelt Dam, occur in the Mazatzal Mountains. Either the source of the clasts no longer exists (it has been eroded away), or it is buried in the lower Tonto Basin, or it is in the current exposure areas of the Apache Group. In any of these cases, streams feeding the arkosic gravels into the Ram Valley/Kitty Joe Canyon area were draining either from or through a highland that no longer exists. The best explanation for the disappearance of the highland lies in the formation of the graben of the lower Tonto Basin. I would argue, based on regional Tertiary relations (Wrucke and Conway, 1987; Conway and others, 1986), that movement on the faults of this graben could have begun as early as 15 Ma and that the basin was well developed by 6-8 Ma. Thus the arkosic gravel of the Kitty Joe sequence could have been cut off from its source as early as 15 Ma. If the source was in the central Mazatzal Mountains, however, it could have persisted, prior to complete removal by erosion, for some time (few million years?) after the initiation of faulting that created the lower Tonto Basin graben.

The third argument for an early Miocene age for the arkosic gravel is that equivalent gravels south and southwest of the study area are overlain by basalts that may be 14-15 Ma (Skotnicki, 1992). However, these basalts have not been directly dated and the 14-15-Ma age derives from correlation with more distant basalts to which there is not a direct stratigraphic tie. These basalts could be younger, particularly because uppermost basalts of the study area - which extend southwest of the study area - are apparently younger than 5.3 Ma, the probable age of the underlying felsic tuff.

Gravel with metavolcanic clasts (Tgm)

Gravels that contain clasts derived from the Mt. Ord area drape large parts of the lower western slopes of Mt. Ord. Slopes underlain by these gravels are smooth, monotonous, and have a light greenish hue. Cobbles and boulders of a wide variety of mafic volcanic rocks and porphyritic granodiorite/quartz diorite are commonly as large as 2 feet in diameter. Lack of road cuts or natural steep cuts precluded a view of undisturbed bedding structure, but it is likely the deposits are poorly bedded and unsorted. These gravels are fanglomerates, likely deposited in steep proximal fans close to the source area. Their deposition was likely triggered by normal faulting along what is now the western base of Mt. Ord (Figs. 1, 2).

Arkosic gravel (Tga)

The Kitty Joe basin contains an accumulation of arkosic gravel on the order of 600 feet thick. Through most of the study area this gravel likely rests on the basin floor directly on Proterozoic rocks (Figs. 1, 2). At places, however, on the eastern margin of the basin it rests on gravel with metavolcanic clasts (Tgm). The most widespread unit of the map area, arkosic gravel extends from the northernmost part of the study area to regions considerably south of the map area where it has been mapped by Skotnicki (1992) as arkosic fanglomerate (his map unit Ofg).

Although the arkosic gravel varies widely in the study area in its clast content, its matrix is distinctly arkosic throughout. Sparse incompetent clasts of coarse-grained granite are present in many places; abundant clasts of finer grained competent granite are present locally - particularly in the northernmost and southwesternmost parts of the study area. Granite probably constitutes from 70% to 95% of the unit and virtually all of this material in most localities is physically decomposed. It was transported and deposited largely as coarse sand to granule fragments - essentially as the individual crystals or small clusters of crystals of quartz and feldspar which crystallized originally in the granite magma. This material constitutes a very immature, poorly sorted, poorly consolidated coarse sandstone to gritstone.

Bedding is poorly to moderately well defined, but there are distinct beds of varying average grain size, varying clast content, and varying lithification. Sedimentary structues were not studied in any detail. Well-cemented cliff-forming beds are rare; hence gravel seems more appropriate to the unit than does conglomerate. As a rule, the gravel

weathers to form smooth slopes and poor outcrop. Deeply incised drainages afford some excellent exposures locally.

Clasts range from pebbles to boulders as large as 5 feet in diameter. Typically, most clasts are moderately rounded and hard (difficult to break), are in the cobble to small boulder range (3-12 inches), and are supported by the arkosic matrix. Clast-supported gravel is rare in this unit. The clasts generally constitute from 5% to 25% of the unit. An accumulation lag of the clasts on gentle slopes suggests, on initial inspection, a greater clast proportion than actually exists in the gravel.

The lithologies of the clasts in the arkosic gravel are tremendously interesting and provide considerable insight into the source regions of the gravel. Paleocurrent data were not obtained and would be very difficult to garner given the poor exposures, the rounded to sub-rounded character of the clasts, and the matrix support of the clasts.

In the northern part of the study area, particularly on the north side of Slate Creek, the arkosic gravel contains an unusually large percentage (as much as 40%) of clasts and it contains unusually large clasts. Large boulders are common. Clasts in this area come largely or entirely from the northwest. I recognize some distinctive Proterozoic lithologies that crop out in the upper Sycamore Creek/MacFarland Canyon area and several miles beyond. Two unmistakable types are rhyolite porphyry of the Pine Mountain Porphyry and banded jasper-dolomite from Ludwig's Cornucopia member (Ludwig, 1974; Wrucke and Conway, 1987). Also present are boulders of Cambrian Tapeats Sandstone. Closest crops of Tapeats are more than 20 miles to the north. It is likely the huge Tapeats clasts in Slate Creek are from a nearer source that has since been eroded away.

Arkosic gravel in the southwestern part of the study area, near Diamond Mtn., contains mostly coherent granite and granophyre clasts. These granitic clasts are leucocratic and resemble rock types of the Diamond Rim Intrusive Suite in western slopes of the northern Mazatzal Mountains. They are not locally derived from granite of Sunflower (Xgs). The granite of Ram Valley (Xgr) is a potential source, but I recognized no granophyre in the granite of Ram Valley.

Throughout the Ram Valley area, in the Kitty Joe Canyon area, and as far north as Iron Dike, the clasts in arkosic gravel are largely from the Troy Quartzite, Apache Group and the Tapeats Sandstone. There are occasional granite clasts, rhyolite clasts, and 'rotten' clasts of a pale green granodiorite/quartz diorite. Dripping Spring Quartzite (probably mostly the arkose member) is the most common clast type, followed by Troy Quartzite, then probably the Tapeats. Also common are clasts of the Barnes Conglomerate and/or Scanlan Conglomerate. My careful search for clasts of the 1.1-Ga diabase that pervasively intrudes the Apache Group was fruitless, except for one diabase boulder (~15 inches) in the modern

alluvium of Kitty Joe Canyon. Since there are no such diabase lithologies in the Tertiary or Proterozoic bedrocks of the region surrounding the study area, I conclude that this specimen came from the arkosic gravel.

My supposition is that Apache/Troy-clast-laden arkosic gravel was brought into this area by stream(s) that flowed to the northwest in an ancestral drainage at least partly coincident with Ram Valley. The source region consisted of deeply weathered granite (probably largely Ruin Granite, but possibly also granite of Sunflower or other granites) unconformably overlain by Tapeats Sandstone, in turn unconformably overlain by Apache Group and Troy Quartzite. This source region lay to the southeast of the study area in or past a highland that has since disappeared through collapse into the lower Tonto Basin graben and through erosion.

It is clear that the arkosic gravel had widely varying source areas, that these source areas all contained more or less weathered granite, and that streams flowed into the Kitty Joe basin from both northwest and southeast. It is likely that the arkosic gravel was deposited in a spectrum of fluvial environments, ranging from proximal fans to distal streams; source distances varied from less than a mile to perhaps several tens of miles. Skotnicki (1992) suggests a fanglomerate setting for the arkosic gravel south of the study area. Much of this granite-clast material may have been derived nearby from western granitic slopes of the Mazatzal Mountains. It is interesting to note, however, that contribution of clasts from Mt. Ord into the arkosic gravel, presumably in a comparable paleophysiographc setting, is insignificant.

Biotite Basalts (Tbx and Tbb)

In the northern part of the study area, there are two biotite-bearing basalt flows (Fig 1) and a number of biotite-bearing dikes and small intrusive masses that were likely sources of the flows (or perhaps just the upper flow). Biotite content ranges from perhaps 5% to 25% and biotite occurs both as phenocrysts and a groundmass phase. These unusual mafic rocks are characterized by high alkali contents, especially K_2O (L. D. Nealey, 1995, written commun.), and by a porous vuggy texture (not smooth-walled vesicles typical of basalts). They are soft, compared to typical basalt flows, and generally weather to low smooth outcrops. However, the thick xenolith-bearing biotite basalt flow (Tbx) forms a pronounced hill north of Iron Dike.

L. D. Nealey (1995, oral and written commun.) collected one sample of the xenolith-bearing basalt at the divide near the highway for which he obtained major and trace element analyses and also did petrography. This is the only analytical work I am aware of on the biotite basalts. In

addition to biotite, the xenolith-bearing basalt contains clinopyroxene both as phenocrysts and in the groundmass (Nealey and Sheridan, 1989). I did not recognize the clinopyroxene in hand specimen. Nealey and Sheridan (1989) mistakenly give their collection locality as Reno Pass, which is four miles to the southeast. They apparently took the name from the Reno Pass quadrangle.

Nealey and Sheridan (1989) call the biotite basalt a latite and note its similarity, especially chemically, to latites at three other localities in the Transition Zone. Despite the chemical affinity to this latite suite, however, the biotite basalt might more properly be classified petrographically as a biotite lamprophyre or a trachyandesite.

The biotite basalt (Tbb) may be one flow fed by nearby dikes and plugs; only a single layer was recognized. However, there are lateral discontinuities in this unit so more than one flow could be present. One can infer the presence of at least three volcanic centers: at the site of dikes in uppermost Slate Creek, at a site of dikes and pronounced thickening of the flow in Cottonwood Basin (Cottonwood bridge site), and at a partly exhumed cinder cone one mile south-southwest of Iron Dike.

The lower flow (Tbx) is very thick (as much as 200 feet) compared to other basalt flows in the area. Its northern, apparently abrupt termination is puzzling. A dike appears to be coming off this termination. There may be both an intrusive and an extrusive component to this body which might be deciphered through further field work. This lower flow contains ultramafic xenoliths which vary widely in abundance, but were present in each of the several localities that I visited. Xenoliths are typically 1-2 inches in diameter; some up to 4-5 inches were found west of Highway 87. Xenoliths appear to be extensively altered and I attempted no systematic identification. Sheridan (Nealey and Sheridan, 1989) identified eclogite xenoliths, apparently in this flow.

Gravel with slatey lithic clasts (Tgsl)

Slatey gravel is composed almost entirely of slabby rocks derived from the Alder Group. The same rock types occur as the largest clasts (as much as 10 inches), as sand of the matrix, and everything in an intermediate continuum. Arkosic material is locally present in proximity to arkosic gravel with which there is some interbedding. The clasts are mostly thinly bedded to laminated and (or) strongly foliated metamorphic rocks: slate, sandstone, graywacke, felsic tuff, lapilli tuff, etc. Potential source areas of these Alder Group lithologies lie to the east, north and west. Cursory observation of imbrication structures suggests stream transport to the south or southwest. The well developed imbrication is highly amenable to future analysis.

This gravel occupies a complex and incompletely understood stratigraphic position within the Kitty Joe sequence in the northernmost part of the study area (Fig. 1). West of the Highway 87 it appears to be the only gravel type between the two biotite basalt flows, whereas, east of Iron Dike the same stratigraphic position is occupied entirely, or nearly so, by arkosic gravel. A small amount of slatey gravel was found 1/2 mile east of Iron Dike beneath biotite basalt (Tbb). In uppermost western reaches of Slate Creek slatey gravel rests depositionally on arkosic gravel.

Whatever the detail, it is clear that the slatey gravel is a tongue entirely within the overall arkosic gravel/basalt succession. It represents a northerly fluvial system feeding into the northern Kitty Joe Basin, entirely separate from the broadly contemporaneous system that brought arkosic gravel from the northwest.

Pyroxene-olivine basalt (Tbp)

Pyroxene- and olivine-phenocryst-bearing basalt caps Iron Dike in the northern part of the study area and extends south to Sycamore Creek east of Sunflower. Although the textures (especially groundmass) and structures of this basalt vary considerably, certain common features persuade me that the variable and disconnected exposures are equivalent. Lithologically, the most important feature is the black pyroxene and olivine phenocryst suite. Nearly as distinctive is the dense, fine-grained matrix which is black on a fresh surface. In places, especially in the southern part of the area, the groundmass is a little coarser and is somewhat mottled with white spots. Stratigraphic position is also important in making the regional correlation. Throughout most of the study area, this basalt type lies directly on the arkosic gravel (or locally on a thin deposit of basaltic cinders) and is overlain only by units of the upper sequence, with the following possible exception.

Although I nowhere found arkosic gravel resting directly on the pyroxene-olivine basalt, there is a hint that it may do so near the cinder cone of biotite basalt one mile south-southwest of Iron Dike. At this locality a biotite basalt cinder cone was completely covered with arkosic gravel and is now partly exhumed. Immediately north of the cinder cone, pyroxene-olivine basalt caps a little ridge. This cap is perhaps 60 to 80 feet lower than the top of the cinder cone which is topped with a little arkosic gravel. Unless there is a fault, for which I found no evidence, between the cinder cone and the pyroxene-olivine basalt cap, the arkosic gravel would appear to have originally also overlain the pyroxene-olivine basalt. This is tentative. If this turns out to be wrong, and the pyroxene-olivine basalt is entirely above the arkosic gravel, the basalt could feasibly

belong to the upper sequence above an unconformity which I suggested above might lie beneath the felsic tuff.

In the central part of the study area (Whiskey Spring and upper Kitty Joe Bridge sites and intervening area) numerous dikes of pyroxene-olivine basalt are identical to the unusually thick flows of the same vicinity. This is almost certainly a volcanic center for this basalt (Fig. 2) and the source of flows to the south. The flow basalt in this locality is probably several hundred feet thick, more than ten times as thick as the southernmost flows. However, the flow(s) capping Iron Dike, considerably north of this volcanic center, are similarly more than 200 feet thick. A few small intrusive bodies east of Iron Dike suggest another volcanic center in the vicinity of Iron Dike. At a site between the two possible volcanic centers - in the cliffs 1 to 1.5 miles south-southwest of Iron Dike - the pyroxene-olivine basalt is completely missing.

Olivine basalt (Tbo)

Two or perhaps three flows of olivine-phenocryst basalt lie between arkosic gravel and felsic tuff on the north slopes of the large mesa on the western margin of the study area. They are of limited areal extent, yet have a maximum thickness of perhaps 70 feet. The flows have highly vesicular, rubbly tops which weather back to form benches. Olivine phenocryst content varies from a few percent to perhaps 10%; olivine is largely altered to reddish iddinsite. Lithologically these flows are closely similar to the basalt flow lower in the section in Cottonwood Basin.

Minor units in the Kitty Joe sequence

A localized enigmatic breccia (Tbr) in the east-central part of the study area (Fig. 2) was fed into the Kitty Joe basin, possibly as a debris flow down the western slopes of Mt. Ord. It appears to be interbedded with arkosic gravel and possibly to contain sand in its matrix from the arkosic gravel. The angular clasts are fairly uniform in size (few inches to 6 inches) and are either from the Proterozoic mafic metavolcanics (Xmv) or from the mafic-clast conglomerate (Tgm). The unit is well-cemented and forms cliffs. Puzzling aspects of this unit are the uniform size of fragments and the source of the brown sandy matrix. There is no clear intermixing of the breccia with the arkosic gravel and the brown sandy matrix actually seems too fine-grained to have been derived from the gravel. Yet the tan, sandy matrix cannot have been formed from mechanical breakdown of the green volcanic clasts in the breccia.

A tiny exposure of rhyolite breccia (Trb) lies apparently within arkosic gravel in upper Slate Creek, but a discordance between arkosic

gravel beds and rhyolite breccia beds suggests a structural juxtaposition of some kind. The light gray to dark gray beds contain obsidian and crystalline rhyolite fragments and are possibly welded in some layers. This unit seems entirely out of place within the Kitty Joe sequence (which contains no rhyolite elsewhere), but I have no better explanation for it. Intuitively, I would like to relate it to the rhyolite volcanic center a few miles to the west, from whence the felsic tuff (Tft) came, but, as postulated above, the felsic volcanic center is about 5 Ma whereas the Kitty Joe sequence is likely 20 Ma or older.

Red to orange, variable basaltic debris was mapped as small lenses at two distinct stratigraphic positions - beneath pyroxene-olivine basalt in upper Kitty Joe Canyon and beneath biotite basalt in Cottonwood Basin. In both cases it is largely cindery material.

There is one small olivine basalt (Tbol) flow beneath biotite basalt in Cottonwood Basin. It is the only olivine basalt in the Kitty Joe sequence other than the capping flows (Tbo). It is a brown-weathering slightly vesicular flow which contains 5-10% iddingsitized olivine phenocrysts.

In the southernmost part of the study area a sandstone/limestone unit (Tsl) is exposed in a small tributary to Sycamore Creek and on the east wall of Kitty Joe Canyon immediately south of the landslide. This unit in upper parts is a mostly reddish, very thin-bedded sandstone; beds vary from silty to gritty. Grains are probably largely of cindery basalt. At depth beneath the sandstone, gray limestone was penetrated in bore holes at the lower Kitty Joe bridge site.

Upper Sequence

Felsic tuff (Tft)

The felsic tuff unit makes a wonderful marker bed in the study area because of its position at the base of the upper sequence, because of its unique lithology, and because of its high visibility. It is a stark white unit that forms cliffs in spite of its soft, porous character. Its pumice clasts are remarkably well cemented to one another, possibly due to slight welding, even though it is an air-fall tuff rather than an ash-flow.

Properly a lapilli tuff, the felsic tuff is composed largely of white ash and white pumice fragments ranging up to 2 inches in diameter. Much less abundant clasts, usually in the 0.5 - 2 inch range, are dense tan to gray rhyolite/rhyodacite and various Proterozoic lithologies through which the rhyolite vented.

The unit is approximately 150 feet thick in the north-facing cliffs of the mesa on the western margin of the map area. It thins and changes character going eastward and southward. In these directions it becomes

increasing more reworked by stream action and diluted with non-tuff lithologies. Southernmost exposures of the unit (few feet to 10 feet thick) actually contain only a few percent felsic ash and white pumice fragments. Most of the material is tan/orange/yellow sandstone which is likely largely of basaltic origin. Nevertheless, the unit retains its marker bed quality by the presence of thin beds containing white pumice fragments up to an inch in diameter.

The felsic tuff laps out against pyroxene-olivine basalt in the central part of the study area (Fig. 2). This is further evidence of a pyroxene-olivine basalt eruptive edifice in this area.

In reconnaissance and on aerial photos I have traced the felsic tuff west of the Kitty Joe Canyon area for several miles; it maintains a thickness of about 150 feet. With little doubt this unit has its source at the rhyolite/rhyodacite volcanic center in the Saddle Mountain/Lion Mountain area only a few more miles to the northwest. It may be continuous, for example, with a unit mapped by Wrucke and Conway (1987) as silicic tuff (their unit Tst). A K-Ar age on a rhyolite plug in this silicic center is 5.3 ± 0.2 Ma (Wrucke and Conway, 1987). On these grounds it seems reasonably certain that the felsic tuff in the study area is approximately 5 Ma.

Cinders and gravel (Tcg)

Lying largely above the felsic tuff, but apparently also interbedded with it, the heterogeneous cinders and gravel unit is limited to the central part of the study area. Near the center of its exposure area, on the west side of Kitty Joe Canyon (SW corner of section 32), this unit contains a thick accumulation of red to tan basaltic cinders. This is likely the site of a small basaltic volcanic center. The cinder beds are dipping 30° to the northeast at one locality and are overlain in angular unconformity by basalt of unit Tbu. Away from this cinder pile the unit contains a wide variety of clasts including cinders, dense basalt (pyroxene-olivine basalt particularly), and various Proterozoic rock types. These heterogeneous beds have a fluvial character.

In the preferred hypothesis developed above, the pyroxene-olivine basalt (Tbp) belongs to the Kitty Joe sequence. If, however, as also discussed earlier, Tbp is entirely younger than the arkosic gravel, it may belong to the upper sequence instead. In this alternative hypothesis, the cinder cone atop Tbp may actually be an integral part of the pyroxene-olivine basalt volcanic center. In this scenario, the Tbp and Tcg would be 5 Ma because the 5-Ma felsic tuff locally lies between Tbp and Tcg and may be interbedded with Tcg.

Basalt of the upper sequence (Tbu) and basalt, undivided (Tb)

A number of basalt flows (Tbu) lie above Tcg or Tft and cap the broad southward dipping mesa west of Kitty Joe Canyon. They were examined only in a cursory fashion. They are likely all olivine basalt and they contain interflow scoria and cinder deposits. Some of the flows and cinder deposits are well exposed in Highway 87 roadcuts westward in Sycamore Canyon.

In the Sunflower area and south of the Sunflower fault on Diamond Mtn, the basaltic volcanic section is much thicker than in the Kitty Joe Canyon/Sycamore Canyon area where the basalts are not likely more than 200 feet thick. Immediately adjacent to Sunflower on the south, basalt of unit Tb is more than 400 feet thick and on Diamond Mtn unit Tb approaches a thickness of 800 feet. It appears therefore that Tb contains not only southward extensions of Tbu, but also hundreds of feet of overlying basalt. These upper sections were not examined on Diamond Mtn and only quickly examined on one traverse on the large hill south of Sunflower. At the latter site the section appears to be entirely basaltic or andesitic and large amounts of volcaniclastic material. In the low hills around the Diamond Ranch north of Sunflower, Tb contains large amounts of conglomeratic basalt.

Gravel, reworked

Gravel (Tgr) in a small exposure between the Diamond Ranch and Sunflower, and near the Sunflower fault, appears to lie on an irregular surface cut into rocks of unit Tb. The gravel has the same general character as arkosic gravel southwest across the Sunflower fault. I suggest the gravel was derived from the arkosic gravel unit following movement on the Sunflower fault and during subsequent erosion of the block on the southwestern side of the fault. I have assigned a Tertiary age to this gravel; it could perhaps Quarternary.

QUARTERNARY DEPOSITS

Perched alluvium (Qap) includes a variety of materials, some locally derived, and some probably transported considerable distances by ancient streams. These alluvial deposits are generally probably a few feet to a few tens of feet thick and are found widely scattered throughout the study area. Perched alluvium is characterized by smooth, gently sloping, or gently undulating surfaces generally at higher elevations, but also at lower 'steps' in places. The stepped or benched character suggests carving of drainages into bedrock at varying times as the region was eroded in late

Pleistocene and Holocene time and the drainages incised. Only remnants of these ancient drainages remain. Some surfaces are suggestive of pediments in which streams wandered on a more or less planar surface rather than becoming incised.

Gravel deposits (Qg) are found along modern drainages on slopes or benches up to 50 feet above drainage bottoms. The deposits are similar to the alluvium of the current drainages and were abandoned as the stream has cut deeper.

Talus deposits are of two types: those that are currently forming (Qt) and those that are on ancient slopes (Qto) that are currently being dissected and destroyed. Modern talus slopes (Qt) are abundant in the study area and range from those on the south slopes of Iron Dike which are rock fall composed entirely of angular blocks, with no soil or vegetation, to heavily vegetated smooth slopes that contain much soil and fine-grained detritus in addition to larger rock fragments.

Alluvial material on benches and flats (Qao) only 5-10 feet above modern drainage alluvium (Qal) are widespread in the Sunflower area. It includes colluvium and sheetwash from adjacent hills and generally has a well developed soil horizon. Except for the extensive soil, Qao is similar to Qal and Qg, but is intermediate in age.

Landslide deposits (Ql) are intermediate in age between older gravels (Qg) and the modern valley-floor gravels (Qal). However, at least one landslide appears to be very close in age to Qal. From arguments developed in the report previously submitted on the lower Kitty Joe bridge site, it appears that the landslide at this side slid out onto stream alluvium essentially at the same level as the modern stream, possibly damning the stream. The toe of the landslide was then eroded away, but the drainage base has been lowered little if any since the time of the landslide.

The landslide at the lower Kitty Joe bridge site was carefully studied and is described in the report on the lower Kitty Joe bridge site. Other landslides received little attention. The large inferred landslide in the northern part of the study area, one-half mile northeast of Iron Dike, is poorly understood and its boundaries uncertain.

STRUCTURAL GEOLOGY

Proterozoic Stucture

As mentioned in the section on Proterozoic rocks, these basement rocks have complex structures, particularly in the Slate Creek area. A discussion of these structures and implications for Proterozoic stratigraphy is beyond the scope of this report. Moreover, since these structures appear to have little or no control on Tertiary structures, there is little point in

discussing them. It is the Tertiary structures that are relevant to this report because the highway will be constructed almost entirely on the Tertiary rocks.

Pre-Kitty Joe Basin Structure

We can reasonably speculate that the earliest Tertiary tectonic activity was that which created the Kitty Joe basin. This was logically normal faulting, creating either a simple fault-bounded graben, or an assymetric basin hinged on one side with a normal fault on the other side. Although such structures were not directly observed in the field, there is indirect evidence that a basin-bounding west-side-down normal fault lies at the base of the western slopes of Mt. Ord and is now buried beneath Tertiary and Quaternary deposits (Figs. 1, 2). There is a suggestion in the physiography of the area and in the configuration of the eastern margin of the Kitty Joe sequence of an ancient north-south scarp which would lie approximately on a line between Cottonwood Basin on the north and central Colcord Canyon on the south. In particular, it appears that this fault line would lie at the base of the steep slopes of granite (Xgr) and metavolcanic rocks (Xmv) where a large exposure of gravel (Qg) covers a gently sloping area east of central Kitty Joe Canyon (near the intersection of Sections 4, 5, 8, and 9).

This fault created the eastern margin of the Kitty Joe basin and initiated rapid erosion of Proterozoic rocks from the Mt Ord area. This resulted in the deposition of the coarse proximal fan material of the mafic clast conglomerate (Tgm) on the western slopes of Mt Ord and into the eastern margin of the new basin (Figs. 1, 2). This study provides no evidence for the nature of the western margin of the Kitty Joe basin.

This early faulting is no younger than about 20 Ma, if arguments made earlier are correct that the Kitty Joe sequence is 20-25 Ma. A regional tectonic event in the Southwest to which this faulting is most likely related is early Miocene extension that resulted in core complex formation in the Basin and Range province.

Pre-Upper Sequence Structure

There is no direct evidence for faulting that may have occured during the basin-fill period. However, ongoing faulting seems likely, particularly because volcanic rocks are interbedded with the basin-fill arkosic gravel. Volcanism and faulting typically go hand in hand. The volcanic centers for Tbb and Tbp lie roughly in a north-south line - parallel to the earlier basin-bounding fault hypothesized above. It is likely the positions of these centers were controlled by a north-south normal fault

active during the basin-fill period. Such a hypothetical fault is shown beneath a dike of Tbb in Fig. 1 (note that the north-south alignment of dikes cannot be shown in Figures 1 and 2). One objective of any further study in the region should be to seek evidence for such faulting. Such faults may explain some of the stratigraphic/structural complexities that vexed me during this study.

I suggest that the basin-fill episode ended sometime after about 15 Ma when faulting began (cf. introductory comments in section on Kitty Joe sequence) which led eventually to the modern horst and graben physiography of the region (Tonto Basin, Mazatzal Mountains, Verde Valley, etc). Faults of this episode are not found in the study area, but the local geologic history reflects that faulting. As a result of this faulting, the source region for the Apache-clast facies of the arkosic gravel was effectively disconnected tectonically. Then followed an extended middle Miocene history of deepening of the surrounding new basins and probably erosional degradation of the Mazatzal Mountains. This would have been a time of non-deposition and perhaps erosion of the Kitty Joe sequence.

Finally volcanism at about 5 Ma, probably related to late faulting in the history of the development of the Tonto Basin and and lower Verde River graben, produced the upper sequence of felsic tuff (Tft) and olivine basalts (Tbu, Tb). In my less preferred alternative, relating to stratigraphic complexities at the boundary between the Kitty Joe sequence and the upper sequence, the pyroxene-olivine basalt (Tbp) would also have been produced about 5 Ma, contemporaneously with the felsic tuff and the cinders and gravel unit (Tcg).

Late Tertiary Faults

The Kitty Joe sequence and the upper sequence were disrupted by at least two distinct faulting events, as reflected by the fault sets mapped in this study. The first event produced generally north-northeast faults and the second generally northwest faults.

The north-northeast faults are few but important. Offsets of the two big faults are on the order of 100-200 feet, down to the west. One of these faults controls the course of central Kitty Joe Canyon and may have played a role in landslide formation at the lower Kitty Joe bridge site (see bridge site report). The other lies considerably west of the highway alignment in the northwestern part of the study area. It is also down to the west. An inferred fault immediately south of Iron Dike, likely of this generation, is also down to the west.

Faulting of the second episode resulted in the distribution of the Kitty Joe sequence into fault blocks within an assymetric graben and in the south to southwest gentle dips of strata thoughout most of the study area

north of the Sunflower fault. The southwestern margin of the graben is the northeast-side-down Sunflower fault, and a similar fault that crosses Sycamore Creek near the campground just east of Sunflower. The combined normal offset on these two faults is approximately 1,500 feet, more than half of which is likely on the Sunflower fault. The other margin of the graben is not so sharply defined. That margin is more or less hinged approximately in the area of Iron Dike and Cottonwood Basin, but is also partly defined by a distributed system of southwest-side down normal faults over several miles in the central Kitty Joe Canyon area. There are several small complex grabens within this fault system.

A system of joints parallel to the northwest-trending faults apparently exists throughout the study area. The joints are poorly expressed in the relatively incompetent Tertiary gravels, but are rather pronounced in large competent rock masses, especially in the large biotite basalt flows in the northwestern part of the area.

Quaternary Structure

Basal and internal breaks of the landslide deposits are likely the only Quaternary structures in the study area, although it is possible that some of the faults described above could be early Pleistocene in age. The landslides are likely Holocene (past 10,000 years) and may reflect Holocene tectonic activity in that earthquakes provide a mechanism for triggering earth failure. There is no direct evidence, however, for any late Pleistocene or Holocene faulting in the study area.

GEOLOGY OF THE HIGHWAY ALIGNMENT

In the following discussion, Quaternary units are generally ignored because they are virtually all loose surficial gravelly material, variations notwithstanding. My work contributes little to the variable clay contents or other material properties of the Quaternary rocks that may be important to the engineering.

Segment F begins about one-half mile southwest of Sunflower. It begins in arkosic gravel which rests at depths of 0 to 50(?) feet on granite of Sunflower. The route then passes through granite of Sunflower, back into arkosic gravel and then across the Sunflower fault. The granite is massive and homogeneous, but does contain a roughly north-trending steep joint set. As the major fault in the study area, the Sunflower fault should be considered to have potential for reactivation, even though it has apparently been inactive through the late Pleistocene and Holocene.

From Sunflower to Sycamore Creek, just past ADOT's 2500 (250,000 feet) location, the alignment is in reworked gravel (Tgr), clastic basalt, and

soil/gravel of the Sycamore Creek floodplain. This is a stretch of little topographic relief underlain by relatively soft, homogeneous, geologic units.

The bridge abutments at Sycamore Creek will be anchored in Tertiary units below Quaternary surfical cover, likely in basalt of Tb on the southwestern abutment and in basalt of Tbu at the northeastern abutment. Engineering of the bridge should account for the northwest fault which will be spanned by the bridge. Drill holes for the southwest abutment area apparently penetrate basalt then arkosic gravel and hard clay-rich rocks (geologic unit ?) and pass into Proterozoic granite bedrock at a depth of about 85 feet. Depth to granite at the northeast abutment, across the fault, is likely 400 to 600 feet.

From Sycamore Creek to the first crossing of Kitty Joe Canyon (at about 2530) the alignment is almost entirely in basalt (Tbu, Tft, Tbp). Going downsection from south to north, cuts will pass through multiple massive basalt flows with soft layers of cinders and flow-top rubble between flows and, near the south abutment if the lower Kitty Joe bridge site, through the soft layer of Tft.

The north abutment of the lower Kitty Joe bridge is sited on the toe of a landslide deposit, discussed extensively in the report on that bridge site. The next one-third mile, almost to location 2550, is also on lower slopes of the landslide. The landslide mass is unstable, subject to creep, especially in wet seasons, and to massive failure in the extreme, for example during an earthquake.

From 2550 to 2600 the road will be supported almost entirely by arkosic gravel which lies everywhere along this stretch either exposed or beneath thin Quaternary cover.

From 2600 to about 2620 there will be extensive cuts into largely arkosic gravel south of the Whiskey Spring bridge site and extensive fill onto arkosic gravel north of the Whiskey Spring bridge site. Dikes of basalt (Tbp) will also be cut south of the bridge site and the south abutment will rest on a vertical contact between arkosic gravel to the west and a very wide basalt dike to the east (see report on Whiskey Spring bridge site).

Immediately north from 2620 there will be a deep cut into a mesa that is capped by thin (as much as 10 feet) perched alluvium (Qap). Beneath this is 50 to 60 feet of soft basaltic debris of the cinders and gravel unit (Tcg; Tgb in the Whiskey Spring bridge site report). The deepest cuts should penetrate well into underlying pyroxene-olivine basalt (Tbp). This dense, fine-grained basalt should provide a large amount of material for fill to the south or for crushed stone to be used as aggregate.

Beyond the mesa the alignment crosses a small graben. The roadway will rest on a little perched alluvium underlain by cinders and gravel and

pyroxene-olivine basalt. On the north side of the graben, north past 2650 and on to the south abutment of the upper Kitty Joe bridge site (2663) the alignment is entirely on pyroxene-olivine basalt with a little Quaternary cover. Moderately deep cuts in this segment should provide additional basalt aggregate.

The south abutment of the upper Kitty Joe bridge site is in arkosic gravel immediately underlying the pyroxene-olivine basalt. Likewise the north abutment is in arkosic gravel. A minor south-side-down fault lies beneath the future bridge span and controls the east-west course of Kitty Joe Canyon for one-fourth mile on either side of the bridge site.

North from the upper Kitty Joe bridge site to about 2720 the alignment is entirely in arkosic gravel, except for a short stretch (200-400 feet) at about 1785 where cuts will penetrate Proterozoic rocks. Proterozoic granodiorite porphyry (Xgd) is exposed on the hill immediately west of the centerline. Just north of this, pioneer roadways made small cuts in weathered schistose rock which may belong to the mafic volcanic rocks unit (Xmv). It is likely the cuts into Proterozoic bedrock will penetrate only soft highly weathered material. Through the rugged topography on north to 2720 there will be extensive cut and fill in the thick arkosic gravel.

From 2720 to 2740 there is extensive alluvial cover (Qap) and the alignment twice crosses a north-south fault. Beneath shallow alluvial cover either basalt (Tbp) or arkosic gravel will be encountered on the west side of the fault, and arkosic gravel will be encountered on the east side of the fault.

Arkosic gravel lies above gently southward dipping biotite basalt from 2740 almost to 2750. Depending on the depth of the roadcut, basalt will presumably be penetrated at some position along this intercept before actually reaching basalt outcrop near 2750. Depth to basalt along this interval could be worked out extrapolating data from the Cottonwood Bridge report and evaluating bore hole data from the area. Just before the Cottonwood Bridge site (~2758) the alignment passes through a thick biotite basalt flow and at the southwest abutment passes down through a thin underlying olivine basalt (Tbol) flow and into underlying arkosic gravel. The northeast abutment is in a complex area where apparent vertical dikes of biotite basalt penetrate arkosic gravel.

Thick arkosic gravel will be almost the only rock type penetrated in any cuts between about 2760 and 2785. A little biotite basalt may be intersected - as dikes or plugs in the first part of this interval, and as a flow within arkosic basalt toward the end of the interval. At about 2785 the alignment is very close to outcrop of the Proterozoic unit Xasu, which in this area contains clay-rich slatey and schistose rocks. Bedding and foliation in these rocks are vertical to steep and strike to the northwest.

The pioneer roadways here cut through surficial materials and arkosic gravel and into the Proterozoic rocks, but these cuts are in and near the bottom of a drainage. If this is an area of fill, which seems likely, the new highway may not acutally cut the Proterozoic rocks.

From 2785 to Slate Creek, the end of segment F, the alignment lies entirely through arkosic gravel except for thin to locally thick (possibly up to 30 feet) surficial cover (Qt and Qto) on ridges and high slopes and alluvium (Qal) in Slate Creek. The detritus in both Qt and Qto is almost entirely basalt from the bold hill to the west underlain by xenolith-bearing biotite basalt (Tbx). The rather thick mantle in places of this basalt detritus leads one initially to suspect the presence of basalt flows. This is not the case; it is entirely loose material and clasts are generally no larger than cobble to small boulder size.

At 2800 the alignment passes through a saddle and near a landslide deposit westward. This landslide is largely inferred and certainly the east boundary near the alignment is inferred. This area received little attention in my study and should perhaps be looked at more carefully for possible impact of this inferred landslide on the engineering and construction.

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GEOLOGY OF THE KITTY JOE CANYON AREA, MAZATZAL MOUNTAINS, ARIZONA

prepared for
Arizona Department of Transportation

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DESCRIPTION OF MAP UNITS

Notes: A query on the map next to a map unit symbol indicates uncertainty either as to the identification of the unit or as to the existence of a separate unit at that location. On the map, a dash and an "i" following several of the basalt unit symbols indicates intrusive basalt (dikes) of lithology identical to the flows.

Qh **Highway (Holocene)**--Highway and adjoining earth materials modified by man. Also includes earth dams and stock tanks

Qal **Alluvium (Holocene)**--Unconsolidated clay, silt, sand, and gravel in active drainage channels. Includes both intermittent and perennial drainages. Thickness to 10 feet

Qt **Talus and colluvium (Holocene)**--Deposits formed by mass wasting processes on steep to moderate slopes. These deposits range widely in character from rock-fall breccia (no soil, no vegetation), found only on the south slopes of Iron Dike, to widespread, relatively stable, vegetated slope veneer in which the rock fragments lie in a matrix of sand and silt. Deposits are actively forming. Thickness to 30 feet

Qao **Alluvium (Holocene-Pleistocene)**--Older unconsolidated clay, silt, sand, and gravel in the inactive parts of modern drainage channels. Usually forms terraces or broad valley fill elevated 5-10 ft above Qal. Floodplain for Sycamore Creek in Sunflower area. Also includes sheetwash from adjacent hills. In Sunflower area has extensive soil development. Thickness to perhaps 30 feet

Ql **Landslide (Pleistocene-Holocene)**--Chaotic masses of rock that have slid down and away from their bedrock source on the order of tens to hundreds of feet. Movement is along a basal listric fault and along numerous internal breaks of great complexity. Thickness to 120 feet

Qto **Talus and colluvium (Pleistocene-Holocene)**--Older deposits formed by mass wasting processes on slopes that are no longer receiving debris but which are undergoing dissection. Thickness to 15 feet

Qg **Gravel (Pleistocene-Holocene)**--Variable deposits of gravel and sand that are generally on benches or slopes less than 50 feet above modern stream beds.

Qap **Alluvium that is perched (Pleistocene)**--Unconsolidated clay, silt, sand, and gravel that lie on smooth gently undulating surfaces "perched" generally at higher elevations in the study area. In many places the morphology suggests the deposits are remnant stream beds; in other places there is a hint of remnant pediment surfaces. Some of the unit is colluvial in character and contains a mixture of local bedrock materials; elsewhere the alluvium is heterogeneous and not derived locally. The most abundant clast types are Tertiary basalt and clasts of Proterozoic rock reworked from the various Tertiary gravels in the area.

Forms gentle stable slopes that have moderate soil development, abundant grass, and sparse trees and chapparal. Thickness to 50 feet

Tgr **Gravel, reworked (Miocene, Pliocene, or possibly Pleistocene)**--Arkose-rich gravel like that of unit Tga. Occurs northwest of Sunflower near the Sunflower fault, where it apparently unconformably and irregularly overlies basalt of unit Tb. Likely derived from unit Tga following movement on the Sunflower fault and extensive subsequent erosion. Thickness few feet to few tens of feet

Tb **Basalt, undivided (Miocene)**--Basalt flows, basalt tuff and cinders, and clastic deposits containing largely basalt fragments. Includes Tbu, a great thickness of basalt above Tbu, and possibly units underlying Tbu. Thick, heterogeneous sequence of basalt near Sunflower on the northeastern, downthrown block of the Sunflower fault. Unit also caps Diamond Mountain 1.5 mi southwest of Sunflower. Largely conglomeratic in the hills near Diamond Ranch. May have been fed in part by olivine-rich basalt dikes (Tb-i) on the east slopes of Diamond Mountain. Thickness several hundred feet

Note: Units Tby and Tbx, shown overlying Tbu in the west-central part of the map area, are photogeologic units of uncertain character; they were not examined in the field. They are not shown in the correlation of map units.

Tbu **Basalt, upper section (Miocene)**--Basalt flows and cinder beds in the central to southern parts of the study area which lie above unit Tft and unconformably above unit Tcg. Composed of numerous flows which are largely, and perhaps entirely, olivine basalt. Flows of this unit cap the large mesa immediately west of Kitty Joe Canyon. Thickness to 200 feet

Tcg **Cinders and gravel (Miocene)**--Poorly-bedded to well-bedded largely alluvial, deposits of cinders, gravel and sand that are largely derived from Tertiary basalt. Pebbles, cobbles, and rare boulders are mostly from a wide variety of basalt types in the area. Proterozoic rocks, largely reworked from Tga and Tgm, locally constitute up to 5% of the clasts. In central part of area unit contains a great thickness of red-brown basaltic cinders which suggest the presence of a large cinder cone. Beds of these cinders dipping as much as 30° are erosionally truncated and unconformably overlain by basalt of unit Tbu. Weakly lithified tan to red sand beds may be largely basaltic volcanic sands, including much scoriaceous material. Heterogeneous unit contains other minor varieties of clastic rock. Thickness 0 to 200 feet

Tft **Felsic tuff (Miocene)**--White to light gray airfall lapilli tuff, possibly water-reworked in places. White, soft, rhyolite to rhyodacite pumice fragments up to 2 inches in matrix of white felsic ash. Thicker, northern parts of section contain abundant rock fragments which are largely dense brown to gray Tertiary rhyolite to rhyodacite, but also Proterozoic clasts of several types. Source is felsic volcanic center in the Lion Mountain/Saddle Mountain area several miles northwest of study area (Wrucke and Conway, 1987). K-Ar age on rhyolite plug near Lion Mountain is 5.3 ± 0.2 Ma (Wrucke and Conway, 1987). Includes brown scoriaceous sands and pebbly basaltic gravel in the central part of the map area; these lithologies lie beneath the white tuff. Unit is absent in parts of the central map area where it lapped out against volcanic constructs of cinders (Tcg) or basalt (Tbp). Unit is very thin (2-6 feet) in southern part of study area where it contains mostly brown to yellow sands likely of basaltic origin, but also sparse interbeds of white pumice fragments. Thickness 2 to 150 feet

Tbo **Olivine basalt (Miocene)**--Two or perhaps three flows of olivine-rich basalt beneath Tft and found only in a limited part of the central map area. Highly vesicular flow-top rubble and red cinders between flows. Thickness 0 to 70 feet

Tga **Gravel with arkosic matrix (Miocene)**--Matrix-supported, tan, granule to boulder gravel widespread throughout the study area. Matrix composed largely of 0.2-1-cm quartz, K-feldspar, and plagioclase fragments from granite source(s) distant from the study area. Generally crumbly granite clasts are less abundant than more indurated Middle and Early Proterozoic clast types. Clast content varies from about 10% to 50%. Moderately well-bedded; poorly to moderately sorted. Generally poorly consolidated, but with local moderately indurated beds. This is a major basin-filling gravel which contains many other interbedded Tertiary units. Throughout most of the map area this unit probably is the basal Tertiary unit resting directly on the Proterozoic basement. On the slopes of Mt. Ord, it also rests on unit Tgm. Clasts in central to southern study area dominated by Cambrian Tapeats Sandstone, Proterozoic Troy Quartzite, and various lithologies of the Proterozoic Apache Group. Clasts in northernmost study area dominated by Tapeats Sandstone and a variety of Early Proterozoic rock types that crop out a few miles to a few tens of miles northwest of study area. Clasts in southwesternmost study area (southwest of Sunflower fault) dominated by granophyre and fine- to medium-grained leucocratic granite. Thickness to perhaps 600 feet

Tbp **Pyroxene-olivine basalt (Miocene)**--Dense, even-grained and fine-grained basalt with a generally smooth light gray weathering surface on which phenocrysts of black pyroxene and red (altered) to locally green olivine are prominently displayed. Dense groundmass is black on fresh surface. Consistently contains 1-2% 1-3 mm olivine and 0.5-1% 1-4 mm pyroxene phenocrysts. Commonly breaks along sub-horizontal but irregular joints into smooth slabs or "loaves", particularly in southern part of study area. Local unusual sweeping fracture pattern is related to irregular flow banding. Caps hill called Iron Dike in northern part of study area and extends to Sunflower fault in the south. Great thickness of Tbp (~200 ft) and abundance of dikes (Tbp-i) in central part of study area suggest presence of volcanic center that likely produced the flows elsewhere in the study area. In central to southern exposures upper few feet are highly vesiculated; vesicles elongated generally southward to southwestward suggest flow in that general direction. Thickness few feet to several hundred feet.

Tbs **Basaltic sediments (Miocene)**--Mostly reddish cindery basaltic material with assorted clastic and volcaniclastic interbeds. Local only and mapped at two distinct stratigraphic positions: below Tbp in central part of area and below Tbb in north-central part of area. Thickness to 30 feet

Tsl **Sandstone and limestone (Miocene)**--Tan to reddish-brown, moderately lithified, thin-bedded sandstone in upper parts and tan to gray limestone in middle to lower parts. Sandstone is likely largely of basaltic origin. Occurs beneath Tbp in the southern part of the study area. Limestone is not exposed at the surface but was intersected in several drill holes at the proposed site of the Lower Kitty Joe bridge. Drill holes did not penetrate the base of the unit. Thickness 0 to 60+ feet

Tbb **Biotite basalt (Miocene)**--Biotite-rich, vuggy, dark gray basalt. Generally fairly soft and weathers to low outcrops having irregular shapes. Locally contains up to 25% phenocrystic biotite that is generally highly visible in outcrop. Biotite grain size varies considerably; rock is not everywhere phenocrystic and biotite is locally more or less of matrix grain size. Biotite generally is well preserved. Proper petrographic name is biotite lamprophyre. Thickens locally, presumably at vent sites. Cinder cone at southernmost exposure of Tbb in central part of study area. Thickness 10 to 100 feet

Tbol **Olivine basalt, lower (Miocene)**--Single, olivine-rich basalt flow. Olivine phenocrysts largely altered (red-brown). Very limited areal extent in north-central part of study area.

Tgsl **Gravel with slatey lithic clasts (Miocene)**--Poorly lithified, poorly sorted, largely clast-supported, red-brown gravel. Slabby clasts (sand, pebble, cobble) of slate, siltsone, sandstone and felsic schist are the major components. Clasts, in various shades of red, green, brown and purple, are largely from the Proterozoic Alder Group. Also present are clasts from the Cambrian Tapeats Sandstone. Matrix largely same material as clasts; minor arkosic matrix. Imbrication suggests stream flow from the east. Largely or entirely between units Tbb and Tbx in northernmost part of study area. Small amounts of this lithology interbedded in Tga beneath Tbb east of Iron Dike were not mapped. Thickness to perhaps 80 feet

Trb **Rhyolite breccia (Miocene)**--Light to dark gray rhyolite breccia with fragments of pumice and obsidian; some highly lithified beds may be welded. Bedded, and apparently interbedded with Tga, but relations obscure. Tiny exposure in northernmost part of study area. Thickness up to 15 feet

Tbx **Biotite basalt with xenoliths (Miocene)**--Biotite basalt similar to Tbb, but generally with less visible biotite and with ultramafic xenoliths. Vuggy, biotite-bearing, medium to light gray, with common mottled appearance and smooth-weathering outcrops. Highly altered ultramafic xenoliths present in most localities, but abundant only locally. Xenoliths usually 1-4 cm. Basalt commonly appears aphyric because of obscurity of altered biotite phenocryts. Columnar jointing common in large masses. Occurs as a thick flow in the northernmost part of the study area. Northern termination of this flow east of the prominent north-south fault has small prong that appears to be a dike. This and nearby dikes of biotite basalt (Tbb-i) are more biotite rich than Tbx. Intrusive versus extrusive character of Tbx and identification of Tbb versus Tbx not entirely resolved in this locality. Thickness to perhaps 200 feet

Tbr **Breccia (Miocene)**--Angular fragments of mafic metavolcanic rock in sparse tan sandy matrix. Clast supported and moderately cemented. Locally forms 10-40-ft cliffs. Likely derived as a debris flow on steep slope composed of Tgm and Xmv. Sandy matrix possibly due to mixing with Tga. These suggestions of nature and origin not entirely satisfactory and are tentative. Central part of map area only. Thickness to 60 feet

Tgm **Gravel with metavolcanic clasts (Miocene)**--Unconsolidated, unsorted, and poorly bedded boulder and cobble gravel; likely deposited in steep proximal fans. Clasts are mostly a variety of Proterozoic mafic metavolcanic rocks; common in many places is a granodiorite porphyry (similar to map unit Xgd) with conspicuous plagioclase and quartz phenocrysts. Matrix materials are of same composition as clasts. Typically has greenish cast due to the chlorite- and epidote-rich greenschist-facies clasts. Lies on lower to intermediate western slopes of Mt Ord; clast types occur as bedrock lithologies in the Mt Ord area. Thickness to 200 feet

Tc **Conglomerate (Miocene, possibly pre-Miocene)**--Tan, lithified conglomerate with arkosic matrix and various crystalline clasts. Contains numerous beds with K-feldspar crystals up to 3 cm. Tiny crop in extreme southwest part of area; more off map to the south

Xgs **Granite of Sunflower (Early Proterozoic)**--Medium- to coarse-grained (5-15 mm) biotite granite. Tan, homogeneous, nonporphyritic and undeformed. Weathers to form smooth bouldery outcrops; bouldery forms up to 15 feet. Age is 1640±15 Ma (Silver, 1965). Occurs along Highway 87 southwest of Sunflower and in a small exposure in southern Ram Valley

Xgr **Granite of Ram Valley (Early Proterozoic)**--Fine- to medium-grained (1-5 mm) leucocratic granite. Red-brown, nonporphyritic, blocky-weathering and locally forms

steep cliffs. Generally undeformed but contains steep shear zones (some mylonitic) trending northeast to north-northeast. Possibly generally biotite-bearing, but mafic constituents typically altered to hematite. Probably akin to the widespread "red" granites (1700 Ma) of the Diamond Rim Intrusive Suite in the northern Mazatzal Mountains and upper Tonto Basin region (Wrucke and Conway, 1987; Conway and Silver, 1989). Widespread in southern parts of Sycamore Creek, eastward into Ram Valley, and in southwestern slopes of Mt Ord

Red Rock Group (Early Proterozoic)

Xrr **Rhyolite**--Wide variety of rhyolite types, most common being ash-flow tuff displaying prominent flattened pumice fragments. Typically in shades of brown or reddish brown. Dense, metamorphosed. U-Pb zircon age of about 1700 Ma (Ludwig, 1974). Occupies axis of Red Rock syncline (Proterozoic) in northernmost part of study area. Thickness several thousand feet

Xra **Andesite**--Andesite or basalt (greenstone) at base of unit Xrr. Thickness about 100 feet

Alder Group (Early Proterozoic)

Xatc **Telephone Canyon member of Ludwig (1974)**--Sandstone, siltstone, and minor conglomerate, shale and tuff. Sandstone is typically light to dark gray or tan and is lithic arenite to, rarely, quartz arenite. Siltstones and shales are gray to purple. Tectonic foliation generally parallel to bedding. Lies stratigraphically beneath the Red Rock Group in the Red Rock syncline. Thickness about 3000 feet

Xasu **Schistose rocks, undivided**--Wide variety of felsic schist, shale, siltstone, sandstone, conglomerate and minor mafic volcanic rocks. These rocks, in general, have a large felsic volcanic component. Includes many units mapped by Ludwig (1974) and by Roller (1987). Structure and stratigraphy of these greenschist facies metamorphic rocks are controversial

Xaq **Quartzite**--Prominent ribs of quartz-rich sandstone within Xasu

Xgd **Granodiorite porphyry (Early Proterozoic)**--Probable hypabyssal porphyry containing phenocrysts of quartz and plagioclase in matrix of quartz, feldspar and ferromagnesian minerals. Phenocrysts 5-10 mm and matrix 1-3 mm. Abundant epidote and chlorite impart greenish cast. Probably metamorphosed along with Xmv, but lacks obvious foliation. Small exposure in central part of map area where it intrudes Xmv. Similar to a common clast type in Tgm

Xd **Dacite (Early Proterozoic)**--Gray-green volcanic rock with fine-grained matrix and sparse 1-mm phenocrysts of feldspar. Small exposure in central part of area adjacent to Xgd. Metamorphosed but unfoliated

Xmv **Mafic volcanic rocks (Early Proterozoic)**--Foliated, green, mafic volcanic rocks metamorphosed in the greenschist facies. Wide variety of rock types and textures ranging from vesicular flows to volcanic conglomerates and from aphyric to porphyritic with abundant plagioclase and/or pyroxene (possibly metamorphosed to amphibole) phenocrysts. Minor, dark, fine-grained rocks likely mafic tuffs. Rocks contain abundant albite, chlorite, epidote, and actinolite which impart greenish cast. May contain intrusive rocks, likely hypabyssal and likely similar to Xgd.

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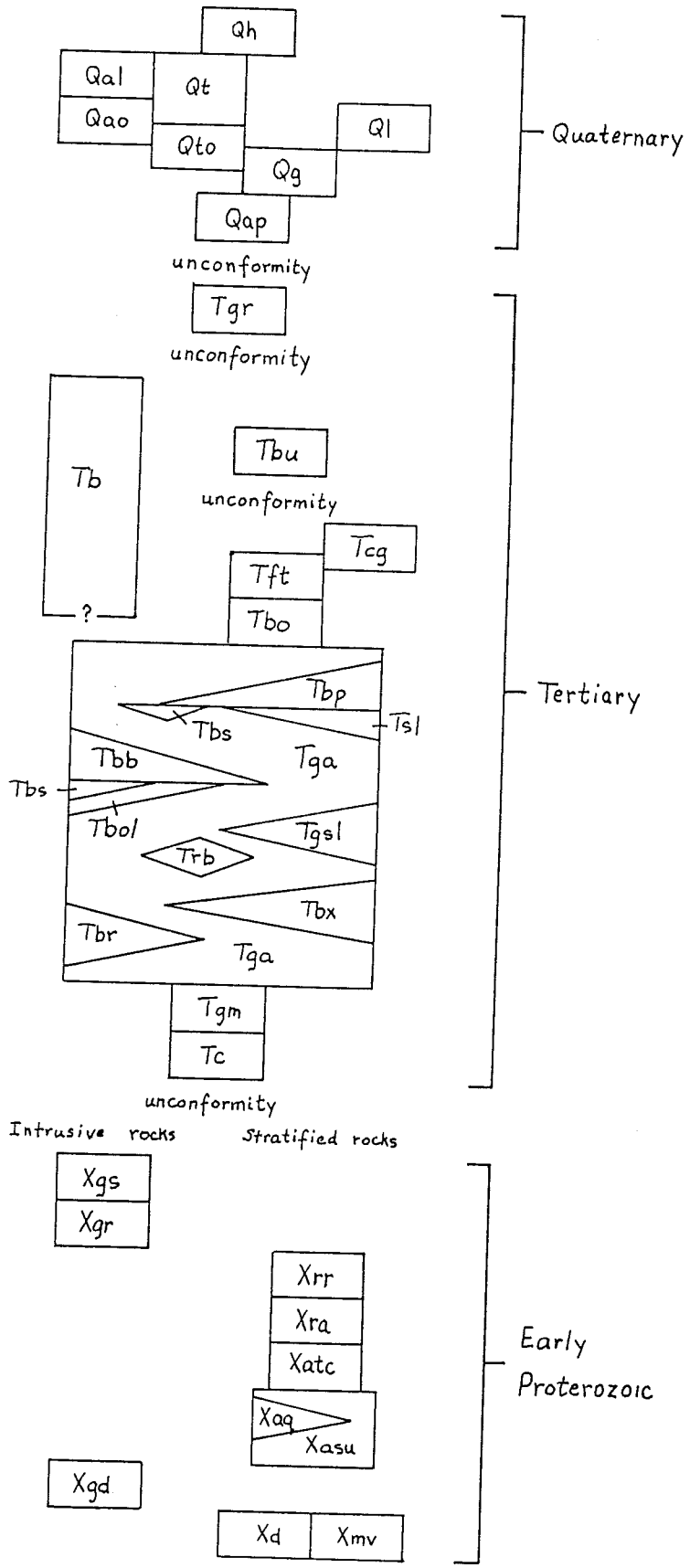
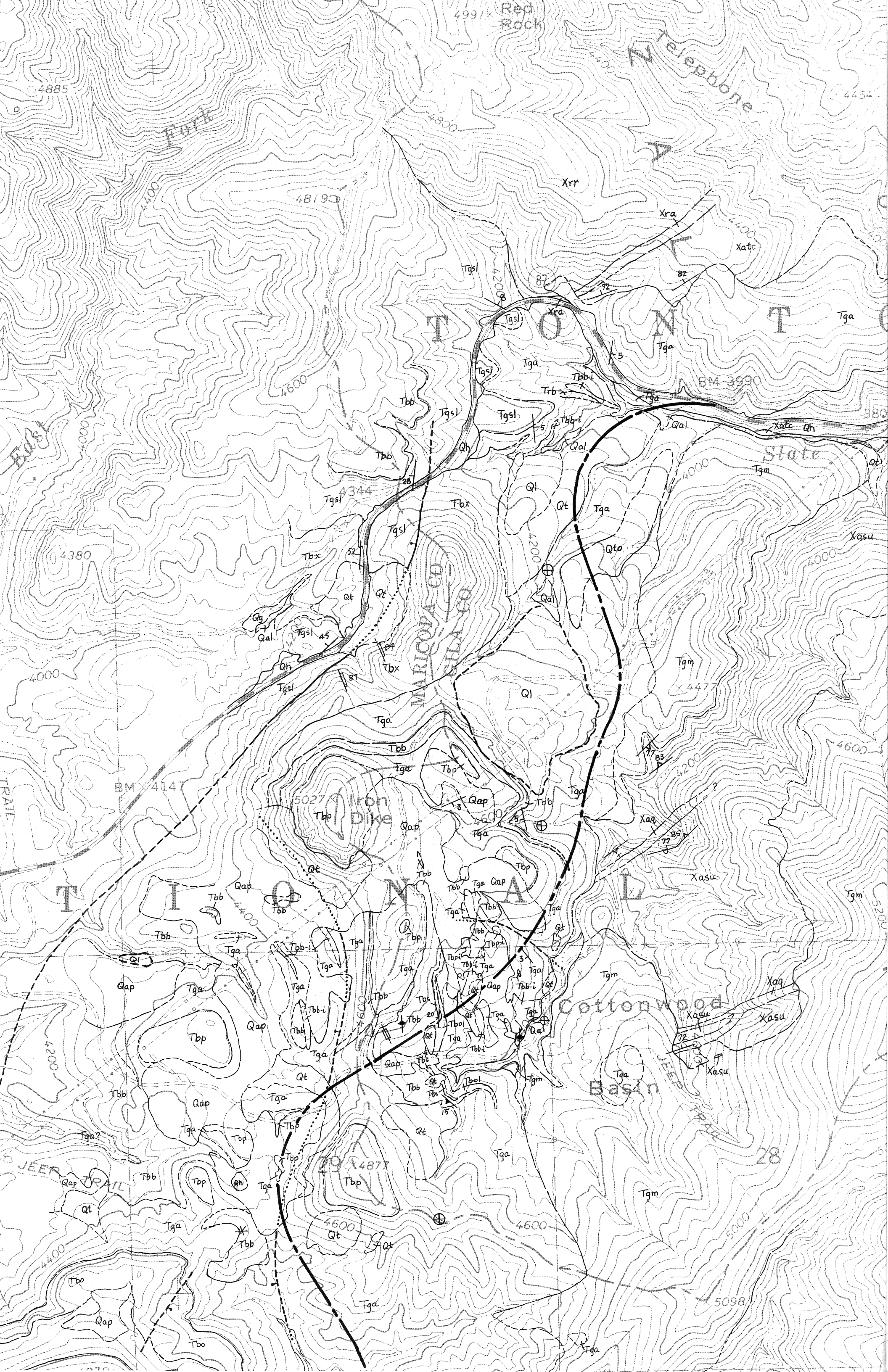
CORRELATION OF MAP UNITS

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Iron Dike
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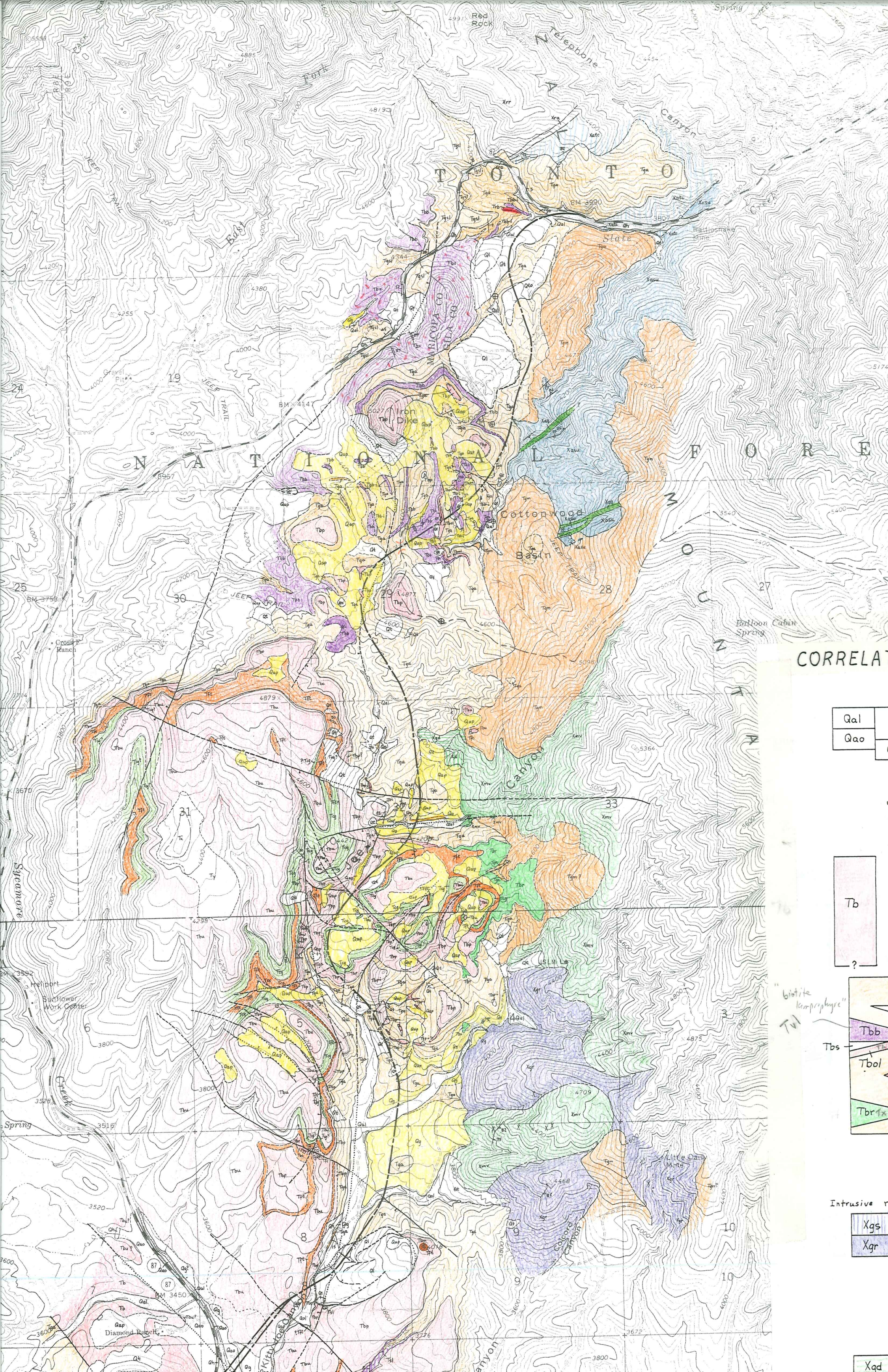
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Sycamore Creek
Heliport
Sunflower Work Center
Diamond Ranch
Little Carr Mine
Carr Canyon
Kitty Joe Canyon
MARICOPA CO
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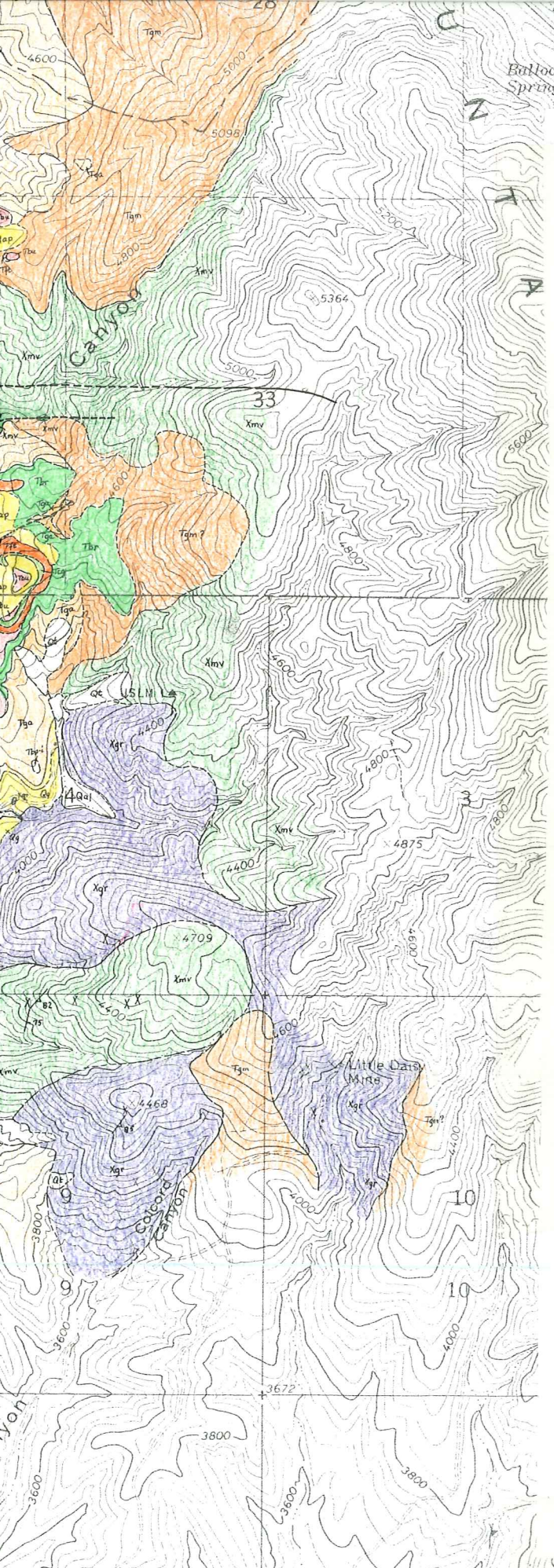

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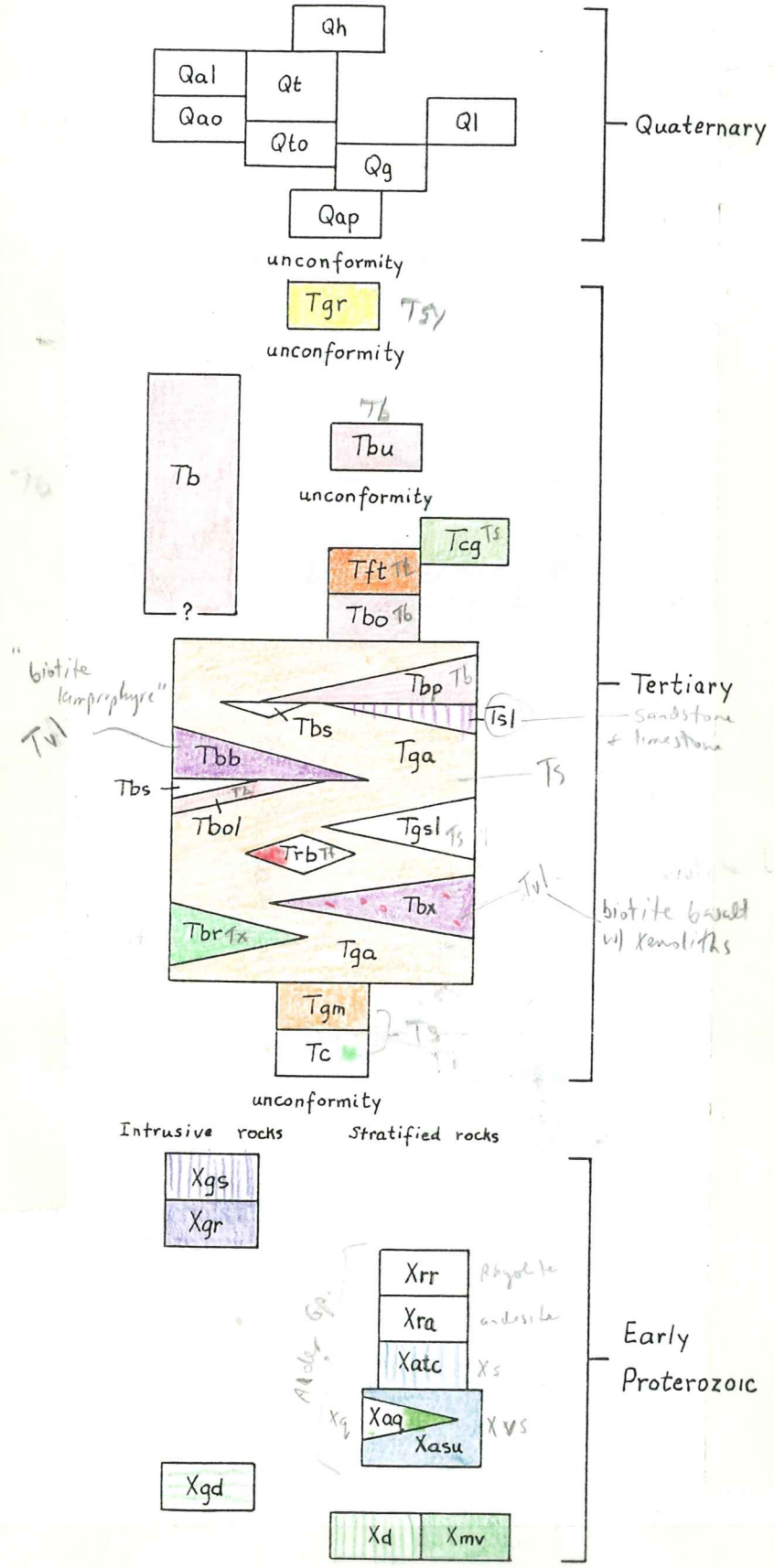

GEOLOGY OF THE KITTY JOE CANYON AREA, MAZATZAL MOUNTAINS, ARIZONA