Internal variations and structure of the Catalina Intrusive Suite, Tucson area, Arizona—a reconnaissance and guide to needed work

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CONTRIBUTED REPORT CR-22-E

November 2022

Arizona Geological Survey

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Manuscript approved for publication in November 2022
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Recommended Citation. Force, E.R., 2022, Internal variations and structure of the Catalina Intrusive Suite, Tucson area, Arizona—a reconnaissance and guide to needed work. Arizona Geological Survey Contributed Report CR-22-E, 7 p.

Cover Photo: Oblique aerial photo of the western Santa Catalina Mountains, Tucson, Arizona (courtesy of Google Earth).

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ABSTRACT

The Catalina Intrusive Suite (formerly ”Catalina Granite”), forming the western end of the Santa Catalina Mountains north of Tucson, post-dates the mid-Tertiary mylonitic deformation of older granitic rocks of the range. Its semicircular outcrop shape is bisected by the Pirate fault, though outliers are present in the Tortolita Mountains. Concentric ring-dikes repeat this shape.

This study divides the Catalina IC into two units, the older of which itself shows two domains. The southern domain of the older unit, mostly of porphyritic coarse granite, contains two bands of problematic mafic segregations and dikes which suggest successive intrusions of granite and mafics. The northern domain of the older unit, mostly of quartz monzonite, shows gravity layering that dips NNE, like most of the Catalina IS’s country rocks. The younger unit, of finer-grained leucocratic granite with a distinct xenolith assemblage, forms a nearly-continuous rim around the older unit. This rim may be considered a three-dimensional carapace if some internal outcrops are part of a “lid”. This rim/carapace is present only as sporadic thin rim-dikes on the north, but thick on the east (the Reef of Rock ring-dike) and south. That is, the Catalina IS is hinged on its northern margin.

The external shape of the Catalina IS as a whole is insufficiently constrained in three dimensions from its outcrop pattern, despite excellent exposure with considerable topographic relief. One possibility is a NNE- tilted “bandshell”-shape (open to the Pirate fault), and if so the thick southern rim of younger leucogranite probably intruded a subsided southern margin of the older unit, in “trap-door” manner. Despite excellent work now about 50 years old, recent work had lagged until dating by Ducea et al. (2020), and many features of the Catalina IS are still insufficiently known and deserve attention. Among these are the age of the younger unit, and the rotation history of the older unit.

INTRODUCTION

The “Catalina Granite” forms the western ramparts of the Santa Catalina Mountains north of Tucson in southern Arizona. At elevations below about 4000 feet it forms an extensive pediment (Bezy 2002), but its outcrops climb abruptly to as much as 7700 feet on Samaniego Ridge and other heights of the main range; a geomorphic character that plays a part in this paper.

The name Catalina Granite is traditional. US Geological Survey papers tended to call it the quartz monzonite of Samaniego Ridge through 1976, at which time the relation to deformed country rocks became clear. Ducea at el. (2020) substituted the term Catalina Intrusive Suite (henceforth Catalina IS) to incorporate some of the compositional variations described herein.

The outcrop pattern of the Catalina IS in the Catalinas forms an irregular semicircle, its diameter defined on the west by the Pirate fault (Figure 1), and some rock types show elements of some concentric structure within it. Some Catalina IS also crops out in the Tortolita Mountains to the west. (Ferguson et al. 2002).

Country rocks into which Catalina IS is intruded are largely Wilderness Granite Suite of Eocene age along its southern margin, and a complex array of Laramide, Paleozoic, and Precambrian rocks separated by faults elsewhere. Locally, Catalina IS forms ring-dikes in country rocks (Force 1997, Suemnicht 1977).

Geologic maps (e.g. Spencer et al. 2000) commonly show only the margin of the Catalina IS in the Santa Catalina Mountains. The map of Banks (1976) is a salutary exception for its southern half. Other works that show data within the Catalina IS include Creasey et al. (1976) and theses from the University of Arizona (Suemnicht 1977 and Hoelle 1976). The latter work includes extensive modal and chemical data, and descriptions of anomalous textures, making it still a most valuable work on the Catalina IS.

The age(s) of the Catalina IS was unclear until recent work by Ducea et al. (2020), due to the poor location data given by Shakel (1972) for a previous U/Pb zircon date. It is now known that part of the complex is 24.9 Ma, consistent with its apparent undeformed character among deformed, commonly mylonitic rocks, suggesting an age younger or coeval to that of the mid-Tertiary mylonitization (Force 1997 and many others). This will be discussed more fully below.

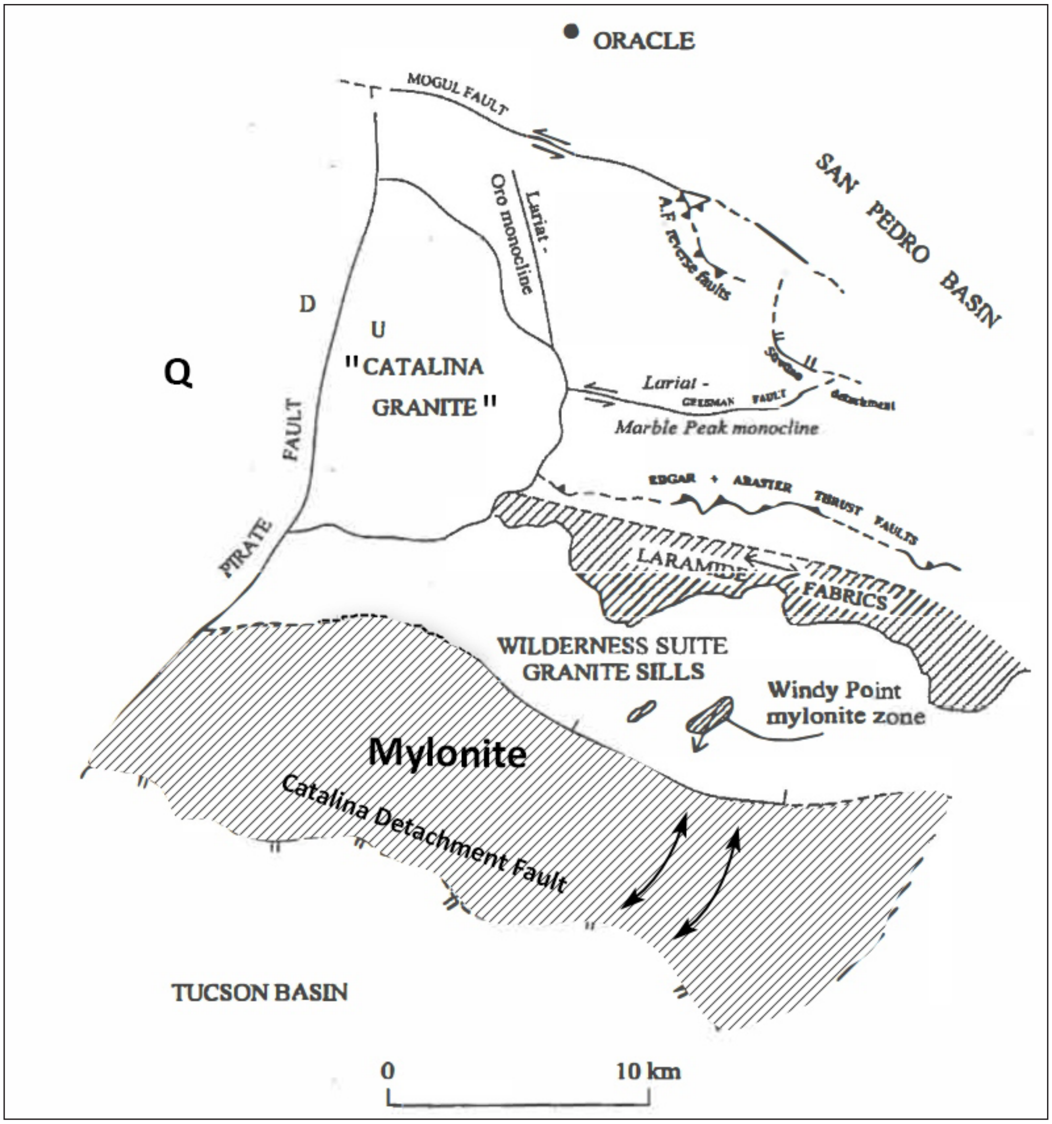

Figure 1. Location of the Catalina IS ("Catalina Granite") and regional features, from Force (1997).

The Catalina IS is mineralogically differentiated in the field from Eocene Wilderness-Suite granitic rocks by its presence of hornblende (though biotite is commonly more abundant) and sphene. Potassium feldspar phenocrysts are characteristic, though equigranular and/or leucocratic granites occur also, indeed define a separate unit described here. Aplitic dikes are common throughout the Catalina IS area, but are not part of the focus of this paper.

Several questions provoke my continued interest in the Catalina IS. For example I introduced (Force, 1997) the possibility that the "Catalina Granite" is a collage of ring-dikes, based on two lines of evidence: first, the presence of a few roughly concentric dikes outside the main mass of granite, and second, the fact that dark tonalitic porphyry occurs both as dikes and xenoliths in granite of this area, suggesting intrusion of multiple granite sheets.

A main purpose of this report is to describe various units and domains present within this ostensibly homogeneous body of granite. The separation into units is based on composition and relative age differences. Domains within a unit differ in structure and composition, sometimes only moderately, but have implications for the structural architecture of the body. However, this report is only of a reconnaissance nature, and it is my hope that differences reported here will lead to further more detailed work.

DESCRIPTION OF UNITS

Overview of unit characteristics

I find that the Catalina IS contains two units, the older of which has two parts. A younger unit forms a nearly-complete rim around an older unit, separating it from country rock except in the northernmost Catalina IS (Figure 2). The younger unit generally differs from the older internal unit in its finer-grained, equigranular, more leucocratic composition. Though sphene and hornblende occur in many specimens, they are sparse. Where xenoliths are abundant, that assemblage is quite different, dominated by sedimentary and metamorphic rocks.

In contrast, the more extensive older unit generally is coarser porphyritic granite or quartz monzonite of more mesocratic appearance, containing sphene and hornblende, and with xenoliths of dark porphyry. This description applies especially to one extensive domain within this unit, apparently underlying another that is defined by density/size layering. These two domains are apparently in concordant contact, so that I treat them as a single unit.

Aplite dikes are numerous throughout the Catalina IS. It is possible that their variations provide additional clues but they are not included in descriptions here.

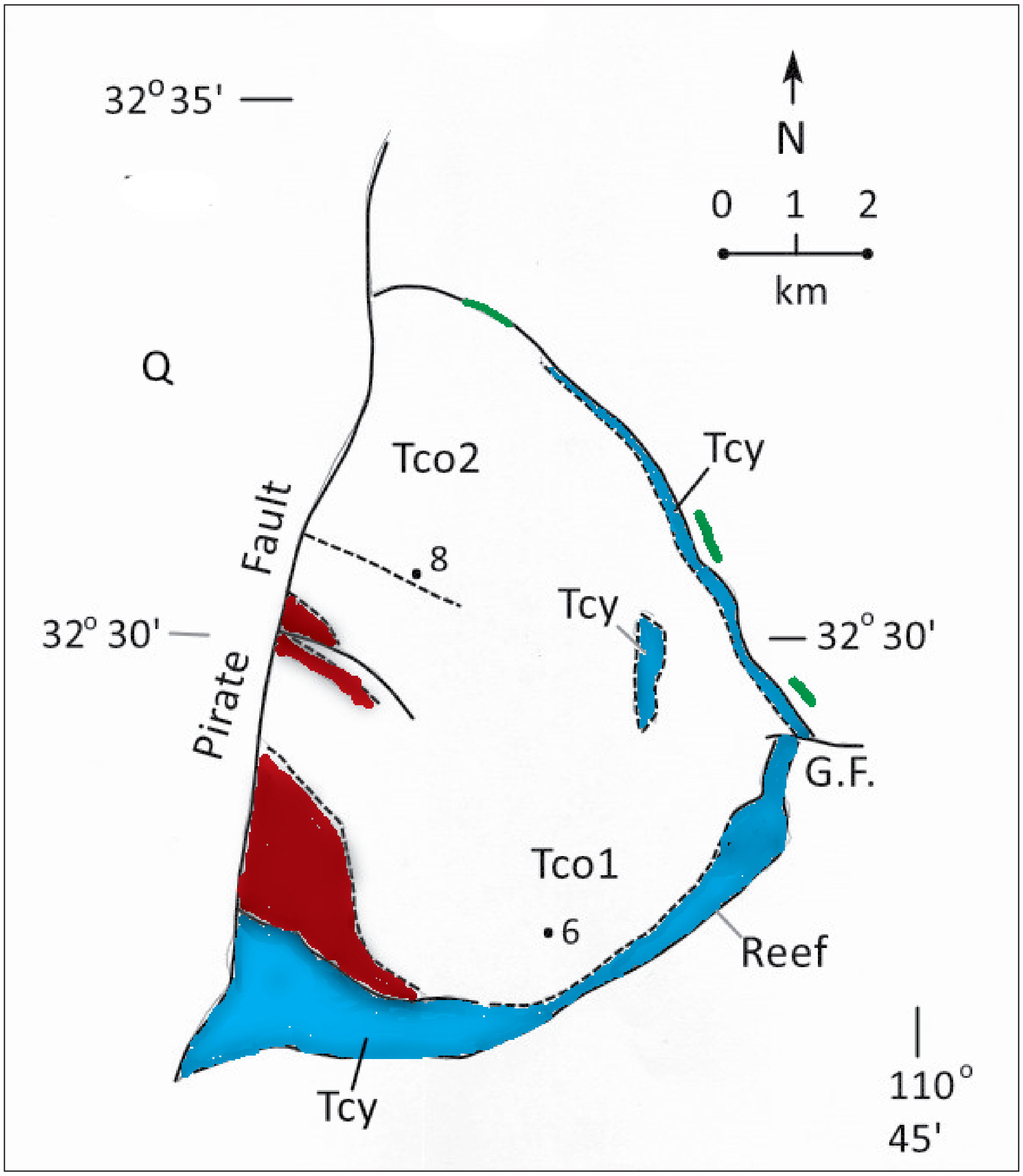

Figure 2. Reconnaissance geologic map of internals of the Catalina Intrusive Suite, plotted on 1:62,500 quadrangle bases (Oracle and Mt. Lemmon). Pirate fault from Banks (1976) and Spencer et al. (2000). Exterior margins of the Catalina IS from Spencer et al. (2000) and my own work on the north, Suemnicht (1977) and my own work on the east and northeast, Waag (1968), Banks (1976) and my own work on the southeast, and Banks (1976) on the south. Distribution of the younger rim unit (in blue) and related external ring dikes (in green) from the same sources, including mapping of Banks (1976) based on xenolith types. The apparent internal repetition of the younger unit is from mapping by Suemnicht (1977) on its eastern margin, but its western margin is unclear so shown in minimalist fashion consistent with my own work. The division of the older units into two domains is also my own work as shown, inherently unclear due to lithologic repetitions except along Charouleau Gap road and its branches. The northern dike-xenolith complex (in red) that crosses Sutherland Wash is from Hoelle (1976) except for relations of xenolith train to dike from my own work. The southern such complex (also red) is from Banks (1976) and my own work.

Unit abbreviations

Tco older unit, divided into Tco1 (southern domain) and Tco2; Tcy younger (rim) unit. Red-shaded area is of southern domain of older unit where xenolith/dike complexes comprise over 20%.

G.F. is Geesaman fault; Reef is reef of rock. 6 refers to specimen Tgc 1406 of Ducea et al. (2020); 8 to Tgc1408. Locations of dotted contacts unclear; dashed contacts approximate.

Older unit

The older, more internal unit of Catalina IS occupies the largest area (Figure 2). I have divided it into an apparently underlying southern domain and an upper northern domain. The southern domain has been considered emblematic of Catalina IS as a whole, and will be described first.

Southern domain of older unit. This domain of the older unit is a grayish porphyritic coarse granite/ quartz monzonite with visible hornblende and sphene. Dark xenoliths, locally forming dense swarms as in the SW part of the body (Figure 2), are common.

In this southern domain, Hoelle (1976) describes "orthoclase" phenocrysts up to 3 cm long, biotite and hornblende up to 1 cm, and sphene to 3-5 mm. Plagioclase composition is An 30-35. Hoelle also gives modal analyses of this domain, which range from quartz 10-25%, potassium feldspar 30-45%, plagioclase 24-34%, biotite 4-19%, hornblende 0-2%, and sphene 0-0.8%. Ducea et al. (2020) also record apatite, magnetite/ilmenite, and zircon. In the current IUGS classification, these rocks would be classified as granite, quartz monzonite, and granodiorite, but I want to emphasize that modal analysis shows that true granites are common. Ducea et al. point out that the mineral assemblage indicates I-type granitoid derivation.

Xenoliths are common in this domain, and are mostly of porphyritic tonalite. Most xenoliths are roughly planar, and these generally dip steeply to the northeast. Figure 2 shows two areas within this domain where such xenoliths comprise 20% or more of the rock, as swarms that are areally co-extensive with dikes of the same composition (cf. Banks 1976). Some such "clots" there could be interpreted as pillows of one semi-crystalline fluid in another, (e.g. Hoelle 1976, figure 9), so that multiple ages of both granitic hosts and tonalite seem possible in the densest swarms, where tonalite can reach 40%.

In the northern such area (Figure 2), Hoelle (1976 figure 18) mapped a "band" 25-40 m wide for 3 km from the Pirate fault arcing ESE through the pediment. Its dark color is due to slightly more mafic and plagioclase-dominant composition. He described" Catalina Granite" intruding it, so called it neither a dike nor a xenolith. As there is evidence of multiple sheets of granite just south of the "band" in the xenolith swarm, it could be a dike in some but older than others. I observe that the band is itself composite, containing parallel dikes of similar material, locally chilled.

The more extensive area of tonalitic dikes and xenoliths is that to the south (Figure 2) near Baby Jesus Ridge. Here also tonalitic dikes are composite, a few with chilled margins, and xenoliths can be lengthy (and/or dikes boudinaged). Possible evidence of two magmatic fluids (granitic and tonalitic) occurs where dikes and xenoliths comprise over 40%. This area is adjacent to the younger unit (Banks 1976), and dikes of its younger leucogranite cut all older units including dikes of these enclaves.

Both xenolith swarms are areally co-extensive with dark porphyry dikes, crowded against the western margin of exposed Catalina IS (Figure. 2). Dikes and xenoliths may have a common origin (probably at depth), and are apparently broadly synchronous with multiple sheets of granite.

Northern domain of older unit. To the north of the southern domain is one characterized by fine layering. Based on simple superposition in a sequence tilted to the NE regionally and in this domain, it could be younger than the underlying southern domain, consistent with top-to-NE indications in the layering. However, it is possible that this domain represents a previous intrusion, and this possibility is consistent with radiometric dating as we shall see.

Fine layering though characteristic is not present throughout this northern domain, the remainder showing the textures and mineralogy of the underlying southern domain. Typical are layers 0.1 - 0.3 meters thick in bundles containing 20-30 layers, as shown by Hoelle (1976, Figure. 8). Toward the top of the domain, such layering tends to be spaced out.

I cannot continue a line on Figure 2 to separate the southern and northern domains of the older unit past the range front of Samaniego Ridge, for lack of sufficient field work and the sporadic nature of characteristic structures. For these reasons I refer to the parts of the older unit as domains. Perhaps future work can convert these domains into formal units.

The exact nature of the layering is problematic; Hoelle (1976) referred to the layers as schlieren, whereas I think they are gravity layers. The basal part of each layer is biotite-rich, the top rich in quartz and feldspars. Some might dispute that the slight density differences can produce such layers, but there is little question that low-angle truncations between layers, indicating top to the NE, suggests a primary magmatic process. Tilting reconstruction shows the layers were originally near-horizontal. Schlieren is a misnomer for these layers, as there is neither shearing nor mixing evident.

The layering itself locally is deformed into folds, mostly open, i.e. preserving the dominantly NE dip. Their presence though suggests that the presumed undeformed character of the Catalina IS is an over-simplification.

The composition of this domain is difficult to average due to its variability. I commonly observed hornblende and sphene within it, even in the layers. Creasey et al. (1976) give a modal analysis suggesting that high biotite correlates with increased plagioclase. Thus this domain at least locally is quartz monzonitic (or even IUGS granodiorite.)

Younger (rim) unit

I am not the first to observe that finer-grained, equigranular, and leucocratic rocks intervene between “typical Catalina Granite” and country rocks in some segments (Hoelle 1976, Creasey et al. 1976; and if properly interpreted, the map of Banks (1976). However, adequate descriptions of these rocks are lacking. I find they form a separate unit. However, I could find no published modal compositions of this unit.

This younger unit forms a near-continuous rim, for 22 km of the 27 km length of the contact of Catalina IS with country rock (Figure 2). It varies in thickness/ width, from over 1 km at the south end of the rim, through about 500 m on the ESE (the Reef of Rock), and 30 m on the east. Over all this distance, only this younger rim unit is in contact with country rocks. However, on the northern margin, this rim unit is absent except as sporadic rim-dikes; that is, the older unit’s coarse granitic rock is in direct intrusive contact with country rocks.

Evidence of the younger age of the rim unit is clear; it sends dikes into both the older unit and country rocks. Indeed it cuts dikes in the older unit in the latter’s southern xenolith swarm.

The younger unit has a distinctive xenolith assemblage, especially when compared to that of the older unit. The difference is most strikingly displayed by the map of Banks (1976—most obvious when colored) on which the contact can be traced on xenolith assemblages alone. The younger unit has xenoliths of sedimentary rocks like quartzite and metamorphic rocks, the latter including Pinal Schist, amphibolite, and calc-silicate rocks. The contrast suggests that the younger and older units have very different intrusion systems.

The younger rim unit is related to numerous ring-dikes of similar material, emplaced in its pre-Eocene country rocks, from the northern margin of Catalina IS (Figure 2) around the northeastern margin (Suemnicht 1977, Force 1997). I propose here that the Reef of Rock, so prominent in the high country of the range for 4000 x 500 m, is another such ring-dike. Together these form a concentric array from where country rocks are Wilderness Suite, north and then west to the Pirate fault. However, where Wilderness Suite is the country rock, dikes of the rim unit tend to be at a high angle to the contact (Banks 1976).

Though both Waag (1968) and I noted the continuity of leucogranites in the rocky headwater wilderness between Shovel Spring and the Reef of Rock, the Reef is separated from the main mass of Catalina IS by an elongate body of deformed Oracle Granite on the east bank of Cañada del Oro. Since this body of Oracle separates the older and younger (rim) units, I consider it a screen, rather than a xenolith. In this view, Reef of Rock is both part of the rim unit and a ring-dike.

Three-dimensional geometry of Catalina IS overall

Since each section of the array of country rocks forms a north-tilted block, and since the young rim unit cuts the faults between them (indeed intrudes the tilted Laramide Geesaman fault; Force 1997), the entire Catalina IS should be tilted with its country rocks, consistent with north and east dips of primary features within it. In addition, emplacement-depth figures from geobarometry given by Ducea et al. (2020) for two samples of the older unit 6.3 km apart show the northern sample 2.6 km shallower, despite the southern sample being 1.0 km higher in elevation. Taken at face value (analytical uncertainty being considerable), the suggested post-emplacement rotation is 23-24 degrees to the NNW. Indeed, as we shall see, the older unit appears to have been back-tilted during emplacement of the younger unit, so that the first stage rotation of the older unit should have been greater. So whatever original shape the Catalina IS had, it has now been tilted.

Based on its outcrop pattern on a topographic plane sloped one way (west) of a mass tilted another way (north), it is impossible to totally specify its original three-dimensional shape. The question is complicated in that the shape of the outer margin (which is that usually mapped) at the crustal level of exposure would be controlled by the younger rim unit, yet the bulk of Catalina IS is in the older unit within it and must control most of the shape. This is treated in the next section.

There are a few clues to the shape of the rim unit from its dips, its ring-dikes, and one apparent exposure of it internal to the body. Suemnicht (1977) in his map of the Cañada del Oro drainage area shows (on his hand-colored map only!) an "internal" facies of fine-grained more-leucocratic granite intermittently forming the east face of Samaniego Ridge, and comments (p. 27) that this continues upslope toward Samaniego Ridge. A three-point calculation from his map suggests the base of this unit dips about 22 degrees east, i.e. 500 ft drop in 1300 ft. I propose that his "internal unit"(Figure 2) is in fact part of the rim unit, dipping too shallowly to reach the bottom of the Cañada del Oro valley (hence its internal distribution) but instead passing above it. His Lightning Bolt fault separates these exposures from the main rim unit.

If Suemnicht's unit is part of my rim unit, it is a fragment of oblique "lid" for the body as a whole, and makes the rim unit a sort of carapace. It seems likely that this carapace has a hemispherical aspect, consistent with dips, concentric features, and ring-dikes, i.e. actually a sort of (tilted) "bandshell" shape open to the Pirate fault.

The original shape of the older unit is more problematic. Internally, the "band" and the "inclusion swarm" to its south suggest partial concentric structure bisected by the Pirate fault, but all the older structures are truncated by the younger carapace unit, as most clearly shown in the Banks (1976) map.

Geometric relation of the two units

The apparent thickness of the younger rim unit is roughly proportional (Figure 2) to distance from the northern contact, where the older unit is attached directly to country rock. If the overall shape of the Catalina IS is hemispherical as suggested in the last section, accommodation space for the intrusion of the younger unit would be provided by sinking of the older unit toward south, i.e. a "trap-door" geometry for intrusion of the younger unit, the older unit being hinged on the north. This would back-tilt the older unit, by an amount that remains unknown until we know the true thickness of the younger unit.

AGE(S) OF THE CATALINA INTRUSIVE SUITE

For decades, the age of the Catalina IS, thought to be mid-Tertiary, was based only on a poorly located, poorly described (Reynolds et al. 1986) U-Ph date on zircon (27 Ma) by Shakel et al. (1977) and various K/Ar dates of that era. New U-Pb dates on zircon reported by Ducea et al (2020) now clarify the age of the Catalina IS considerably. Two of these dates plot in the part of Catalina IS covered in this report (Figure 1), and show ages of ca. 24.9 Ma (late Oligocene).

I have used the supplementary data reference in Ducea et al. (2020) to plot their sample locations on my figure 2. Both sample localities are in my older unit, consistent with the petrographic information given by Ducea et al. for their samples. However, one of them (CGA 1408) plots in the northern domain of my older unit, whereas the other (CGA 1406) plots in the underlying southern domain. Given the considerable accuracy of their analysis, the northern domain may be the older, by ca. 0.3 Ma.

The younger unit still remains undated except by K/Ar work, mostly by Creasey et al. (1976), some of whose samples do plot within the younger unit in the Santa Catalina Mountains. Locality IV (ML61) of Creasey et.

al (1976) was reported with K/Ar ages of ca. 22 Ma for biotite and 24 for hornblende. Their locality VIII (BR16) showed an age of 23 Ma for biotite. These probably-subsolidus dates suggest similar ages for the younger and older units. However, this remains to be determined.

OTHER NEEDED WORK

Mapping presented here needs to be upgraded in at least three regards—the screen of pre-Tertiary rock between Reef of Rock and Cañada del Oro, the rim unit in Oracle quad south of Charouleau Gap, and the eastward continuation of the boundary between northern and southern domains of the older unit. Attention needs to be directed toward the younger (rim) unit of the Catalina IS, with regard to age and emplacement geometries. Evidence and suggestions presented here show the promise of paleomagnetic work in the Catalina IS, to untangle the sequence of tilting and successive intrusion. Detailed work on successive intrusion using tonalitic markers also seems promising.

Acknowledgments

The interest of George Davis and Bill Dickinson helped me extend my own interests westward to the Catalina IS. I suspect that Ed McCullough earlier inspired students to work on this body, works I encountered in the Antevs reading room at Univ. Arizona Geosciences. Great mapping by Norm Banks is adequately referenced, but I wish USGS had published his map in color!

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