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CRUSTAL EXTENSION AND THE PEAK COLORADO RIVER GRAVITY HIGH, SOUTHERN SACRAMENTO MOUNTAINS, CALIFORNIA: A PRELIMINARY CORRELATION

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ABSTRACT

Extreme Tertiary crustal extension is well documented in the Colorado River extensional corridor along the California-Arizona border and in southern Nevada. A magnetic and gravity high described by Simpson and others (1990) tracks the zone of maximum mid-Tertiary crustal extension along the west side of the Colorado River for ~150 km. Along that length, the gravity anomaly has a width that varies from 10 to 20 kilometers and an amplitude of 10 to 20 mGals above background levels.

The peak of the Colorado River gravity high, which is an additional 10 to 20 mGals above the common level of the anomaly, is located in the southern Sacramento Mountains. One hundred and twenty new gravity measurements around and across the Sacramento culmination have thoroughly defined its size and shape. In the northeast and southwest directions, parallel to the direction of crustal extension, the gradients of the anomaly are steep and symmetrical. The shape of the anomaly indicates that the source body lies in the upper crust, and that this body could be 10 to 20 km across in the northwest-southeast direction. The extreme peak of the anomaly lies directly above recently recognized Tertiary diorite, which may be close in age to the time of most rapid extension. Based on reconnaissance geologic mapping these rocks are not exposed in large volume at the surface. But they may be dense enough to account for a gravity anomaly of this magnitude and will provide surface density measurements necessary for constructing a model of the source body. The relationship between the gravity high, Tertiary extension, and crustal magmatism is currently under investigation; the following is a report of observations made from newly acquired geologic and gravity data.

INTRODUCTION

The Cenozoic deformational history of the eastern Mojave and western Sonoran Deserts is dominated by extreme crustal extension along the 100-km wide Colorado River extensional corridor (Howard and John, 1987) (Fig. 1). Low-angle normal or detachment faults are exposed around domal core complexes in the central part of the corridor, including the Whipple Mountains (Davis and others, 1980; Davis and Lister, 1988), Chemehuevi Mountains (John, 1987a), and Sacramento Mountains (McClelland, 1982; Spencer, 1985). Regionally, major mid-Tertiary extension involving the upper and middle crust was accomplished along brittle, northeast-dipping detachment faults with upper plate transport to the northeast (Davis and others, 1980; John, 1982; Howard and others, 1982, Spencer, 1985). The headwall breakaway of the fault system lies at the west side of the corridor (Howard and John, 1987), and field relations indicate that basal fault(s) initially cut to depths of 10 to 15 km along the regionally developed Chemehuevi-Whipple detachment fault system. Cumulative slip on the detachment increases to the northeast across the corridor and totals ~ 50 km (100%) (Howard and John, 1987). Geologic and seismic-refraction data (McCarthy and others, 1991) suggest that the fault system lies at a depth of less than 3 km under the Mohave Mountains and is rooted further east under the unbroken Hualapai Mountains and Colorado Plateau.

Initiation of crustal stretching in this region began at ~ 23 Ma. This estimate is based on a variety of data, including the K-Ar ages of the oldest volcanic units in the synextensional Tertiary basins (Brooks and Martin, 1985; Howard and John, 1987; Spencer and Reynolds, 1991), crystallization ages of the oldest synextensional plutons in the lower plate of core complexes (Anderson and others, 1988; Foster and others, 1990), and the oldest $^{40}Ar/^{39}Ar$ cooling ages directly related to denudation of footwall rocks (John and Foster, 1993; Foster and others, 1990). The period of rapid extension that led to formation of the metamorphic core complexes and adjacent basins in this region ceased by roughly 13-14 Ma, based on the age of untilted volcanic rocks, thermochronology, and basin development (Howard and John, 1987; Davis and Lister, 1988; Richard and others, 1990; Foster and others, 1990, 1991; Spencer and Reynolds, 1991; Simpson and others, 1991).

The asymmetry of upper and mid-crustal faulting within the corridor has prompted numerous geologists to propose a simple-shear model for lithospheric extension in this region (Spencer, 1985; Howard and John, 1987; John, 1987a; Davis, 1988; Lister and Davis, 1989). Seismic reflection and refraction studies, however, suggest structural symmetry at depth. The middle crust is apparently domed beneath the core complexes, whereas the base of the crust shows little relief (McCarthy and Thompson, 1989; McCarthy and others, 1991; Wilson and others, 1991). From their interpretation of Bouger gravity anomalies Thompson and McCarthy (1990) argue that additional crustal-density material is required to replace material advected to the sides during extension. Lateral flow of the lower crust (Block and Royden, 1990) and addition of low-density material derived from the mantle (Gans, 1987; Thompson and McCarthy, 1990) are two mechanisms proposed for maintaining the flat Moho noted today beneath the core complexes.

Evidence for magmatic inflation of the crust associated with extension comes from documentation of synextensional magmatism found throughout the Cordillera. Tertiary plutons and/or dike swarms are present beneath virtually every highly extended terrane or core complex in the Colorado River extensional corridor, as reviewed in an unpublished manuscript by R.W. Simpson and colleagues. Examples from south to north include (see Figure 1), the Harquahala Mountains, west-central Arizona (Richard and others, 1990), the Swansea plutonic suite in the Buckskin Mountains (Bryant and Wooden, 1989; Bryant and others, 1993), rocks from the War Eagle complex in the northern Whipple Mountains (Wright and others, 1986; Davis, 1988; Anderson, 1988; Anderson and Cullers, 1990), and those in the Chemehuevi (John, 1987b), Sacramento (Spencer and Turner, 1983; Spencer, 1985; Foster and others, 1990), Dead and Newberry Mountains (Wooden and Howard, pers. comm. 1992), Homer Mountain (Spencer, 1985), and Eldorado Mountains (Anderson and others, 1972; Falkner and others, 1993; Gans and Landau, 1993).

COLORADO RIVER GRAVITY HIGH

Associated with the Colorado River extensional corridor are linear gravity and magnetic highs that extend along the west side of the Colorado River for approximately 150 kilometers (see Mariano and others, 1986; John, 1987b; John and others, 1988; Mariano and Grauch, 1988; Simpson and others, 1990, also unpublished data; Klein, 1991; Mikus and James, 1991). Along its length, the isostatic residual gravity anomaly has a width of 10 to 20 kilometers and an amplitude of 10 to 20 mGals above background levels (Fig. 1). Culminations in the gravity high lie over parts of the Eldorado, Newberry, Dead, Sacramento, Chemehuevi and Whipple Mountains core complexes. The peak of the Colorado River gravity high (CRGH), which is 20 mGals above the ambient level of the CRGH, is located over the southern Sacramento Mountains. Based on regional reconnaissance density measurements, the only rocks dense enough to cause these anomalies are sparse mafic intrusions dated between 22 and 14 Ma (Simpson and others, 1990). These workers' analysis of the exposed distribution of dense rocks suggests that there is insufficient areal exposure to fully account for the anomaly, and they hypothesize that concealed, dense Tertiary intrusions and other middle and lower crustal rocks were uplifted during extension.

R. Simpson and others (pers. comm., 1993) have also examined the aeromagnetic data for the Colorado River extensional corridor (Mariano and Grauch, 1988), and found that the magnetic anomalies generally coincide with the gravity highs, although they do not necessarily imply the presence of mafic plutonic rocks.

GEOLOGIC FRAMEWORK OF THE SOUTHERN SACRAMENTO MOUNTAINS

The Sacramento Mountains core complex lies to the south and west of Needles, California (Fig. 2a) in the central part of the extensional corridor, in the region of maximum crustal extension (Howard and John, 1987). In the west-central part of the range the Sacramento Mountains detachment fault, a regionally developed low-angle normal fault, separates hanging wall crystalline rocks and Tertiary volcanic and sedimentary cover from a footwall of Proterozoic and younger crystalline rocks with localized mylonitic fabric (McClelland, 1982, 1984; Schweitzer, 1991; Simpson and others, 1991). The Sacramento Mountains detachment fault has been correlated locally with the Chemehuevi detachment exposed to the south (John, 1987b) (Fig. 2a).

Previous work in the southern Sacramento Mountains area was carried out by the Southern Pacific Land Company (Coonrad, 1960; Coonrad and Collier, 1960), and compiled on the Needles 1° x 2° sheet (Bishop, 1964). McClelland (1982, 1984), Foster and others (1990), Simpson and others (1991), and Schweitzer (1991) studied areas north of Monumental Pass (Fig. 2a), but the structural history of the southern Sacramento Mountains has not been described since the work of the Southern Pacific Land Company. Preliminary field studies in the southernmost Sacramento Mountains, between Lobecks' Pass and Monumental Pass, indicate that the footwall rocks to the Sacramento Mountains detachment fault include a suite of granitoid rocks including hornblendite and gabbro, diorite and granite. These rocks, informally called the Sacram suite, intrude Proterozoic gneiss and granite, including protomylonitic rocks in the Monumental Pass area. Rocks from the Sacram suite are texturally and mineralogically indistinguishable from a small stock in the Chemehuevi Mountains ~5 km to the south (Fig. 2a) that gives an U-Pb zircon age of ~19 Ma (Mukasa and John, unpublished).

Textural features of the Sacram suite suggest that it is tilted an unknown amount toward the southwest. Westernmost exposures of the suite are dominated by hypabyssal granite and quartz monzonite. Five to eight kilometers to the east the apparently structurally deepest exposures of the suite are characterized by mixed mafic and felsic rocks (granite and diorite, gabbro and hornblendite), and purely mafic plutonic rocks. Here the Sacram suite rocks show spectacular field and petrographic evidence of magma mingling between various mafic and felsic bodies. This includes fine-grained elliptical and spherical mafic enclaves commonly with crenulate margins or quenched rims, and mantled quartz xenocrysts and quartz-feldspar aggregates in the diorites. These textures are common in other documented synextensional plutons in this region (Larson and Smith, 1990; Falkner and others, 1993).

The Sacram suite rocks are clearly in the footwall to the Chemehuevi and Sacramento Mountains detachment fault(s) to the northeast of Lobecks' Pass, but occupy an unknown structural position relative to the Chemehuevi detachment fault to the west. McClelland (1982, 1984) originally mapped the Sacramento Mountains detachment fault cutting through Monumental Pass, placing the southern Sacramento Mountains in the hanging wall. More recent work by Simpson and others (1991) was interpreted to suggest that the Monumental Pass fault is a steeply dipping strike-slip fault, rather than a low-angle normal or detachment fault. Despite controversy as to their relative structural position, rocks of the Sacram suite locally intrude Proterozoic gneisses with a steeply dipping mylonitic fabric, and themselves bear only cataclastic or low-temperature solid-state fabrics.

GRAVITY OBSERVATIONS

One hundred and twenty new gravity measurements around and over the culmination of the Colorado River gravity high have refined the size and shape of the anomaly and allow rough estimates to be made about the size and location of its source body. The isostatic gravity level at the peak is 29 mGal, which is 20 to 40 mGal above the general range of values outside the CRGH. Gradients of gravity anomalies are steepest over edges of anomaly sources, which could mean the dense body causing this anomaly is 10 to 20 km wide in the northeast-southwest direction. There appears to be symmetry of the anomaly in the northeast-southwest directions, which could be similar to the mid-crustal symmetry observed in seismic studies.

In the northwest-southeast directions, gradients up to the Sacramento culmination are much more gentle. The peak rises gradually to 10-20 mGal above the general level of the CRGH, indicating that the source body of the extreme peak may be elongate in that direction, but is closest to the surface or thickest in the southern Sacramento Mountains. A preliminary model by R. Simpson (pers. comm., 1993) suggests that this body lies at or within a few kilometers of the surface.

Despite recognition of the massive gravity and magnetic high in the Colorado River extensional corridor, previous traverses throughout the northwestern Chemehuevi Mountains have unveiled few rocks at the surface of sufficient magnetic susceptibility and density to produce the geophysical anomalies. The mafic rocks of the recently discovered Sacram suite in the southernmost Sacramento Mountains seem ideal candidates to generate such an anomaly. In fact, the extreme peak of the high (Fig. 2b) lies directly above mafic diorite (Td, in Fig. 2a.). If the mafic rocks of the Sacram suite are the source of the anomaly, it will be possible to construct a model from the gravity data showing the size, shape, and nature of the boundaries of this dense pluton.

SUMMARY

The Colorado River gravity high is most likely caused by magmatic intrusion related to extension. Though the exact nature of that relationship is unknown, constraints can be made on the timing and interplay between the two by integration of gravity data interpretations and documentation of surface relationships. While modeling of the gravity anomaly will more precisely delineate the source body, it can presently be inferred that the culprit is probably Tertiary mafic rocks exposed at the surface. The margins in the northeast-southwest directions have a strike that is perpendicular to the direction of slip on the regionally developed detachment system, though how this body is related to the 100% extension accommodated in the corridor is unclear at this stage of the investigation. Future interpretation of the gravity data guided by exposed structural relationships will provide additional clues as to the causal relationships between magmatism and crustal stretching.

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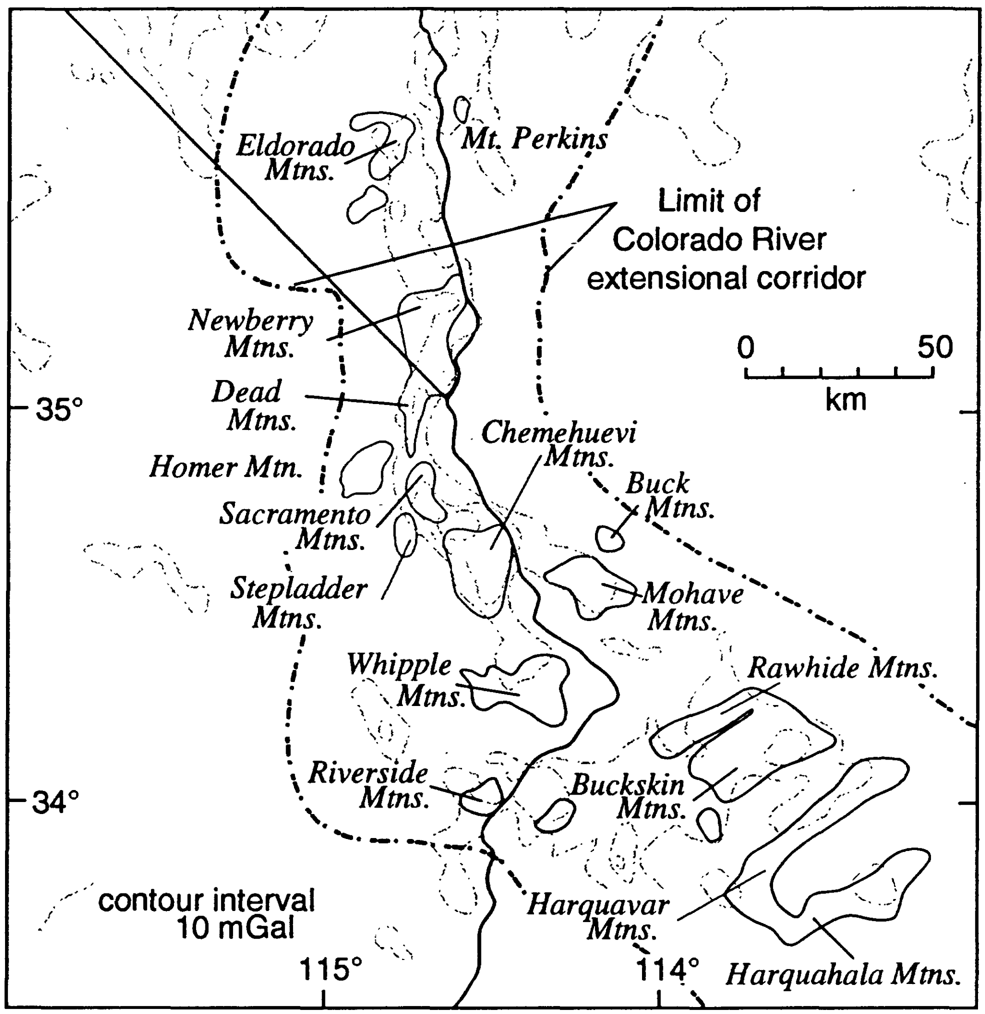


Figure 1. Outline of the Colorado River extensional corridor showing locations of mountain ranges referred to in the text (after Howard and John, 1987). Dotted lines are isostatic residual gravity contours with values 0 mGal (simplified from Mariano and others, 1986; R. Simpson personal communication, 1993).

EXPLANTION

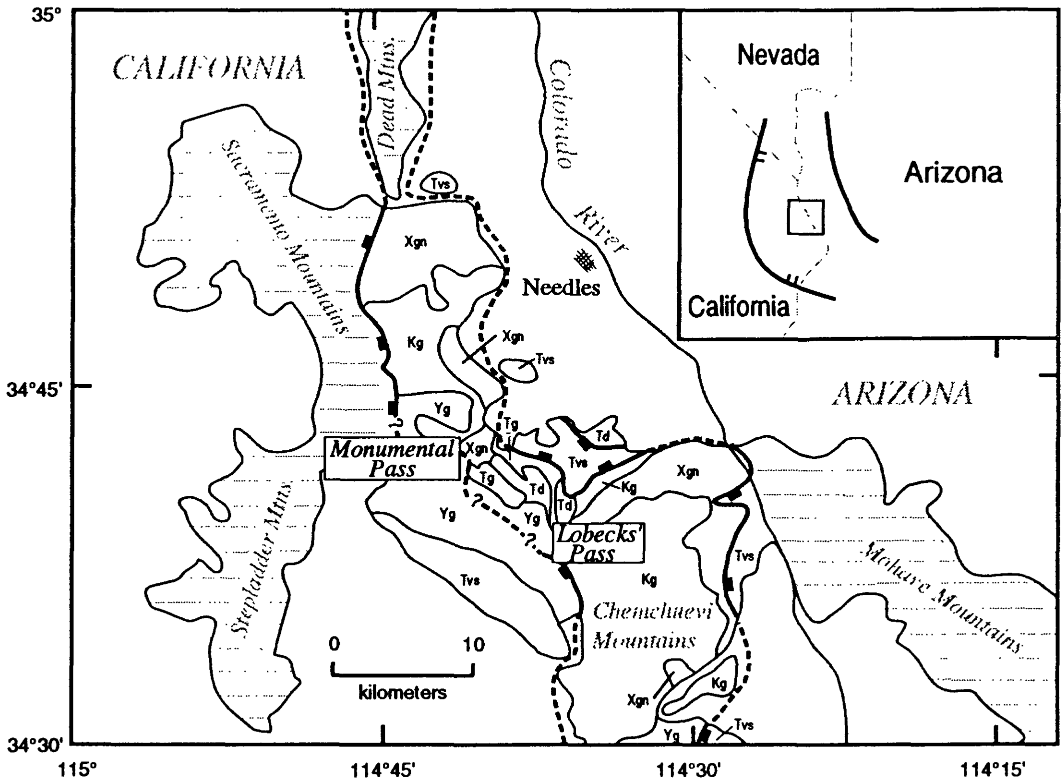
	Quaternary alluvium
Tvs	Tertiary volcanic and sedimentary rocks
Tg	Tertiary granite and granodiorite
Td	Tertiary diorite, gabbro, and hornblendite
Kg	Cretaceous granodiorite, quartz diorite and diorite
Yg	Proterozoic granite
Xgn	Proterozoic gneiss
	detachment fault (dashed where approximate or concealed)

Figure 2.

A. Generalized geologic map of the central and southern Sacramento and northern Chemehuevi mountains, compiled from John (1987b and unpublished), Coonrad (1960) Coonrad and Collier (1960), McClelland (1982, 1984), Schweitzer (1991), and Simpson and others (1991). Inset shows relative position of the Sacramento Mountains area to the Colorado River extensional corridor between heavy dashed lines. Geology not shown in horizontal ruled areas.

B. Isostatic residual gravity map of the peak of the Colorado River gravity high. Contour interval 4 mGals

A.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CALIFORNIA
Dead Mtns.
Colorado River
Nevada
Arizona
California
Sacramento Mountains
Tvs
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Needles
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Td
34°45'
ARIZONA
Monumental Pass
Lobecks' Pass
Steepladder Mtns.
Mohave Mountains
Chemehuevi Mountains
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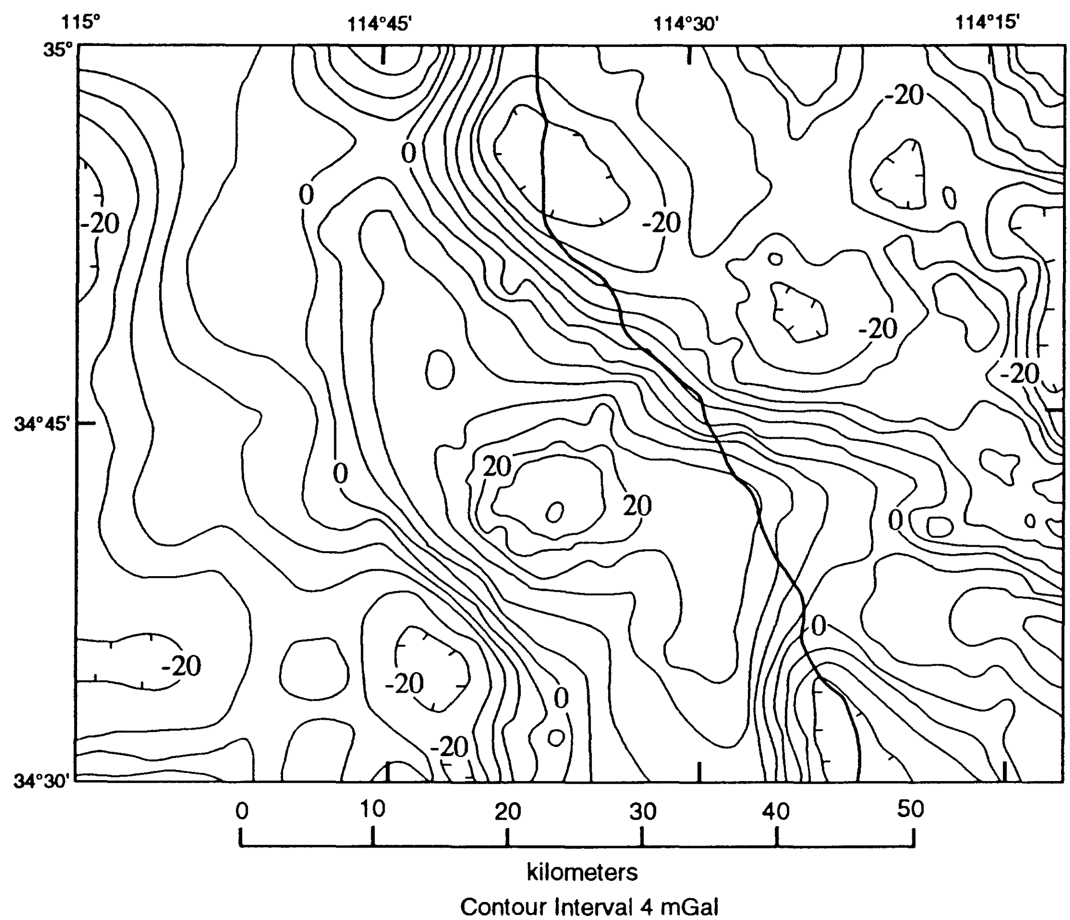
B.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