NASA

Technical Memorandum 79548

Martian Canyons and African Rifts: Structural Comparisons and Implications

(NASA-TM-79548) MARTIAN CANYONS AND AFRICAN RIFTS: STRUCTURAL COMPARISONS AND IMPLICATIONS (NASA) 34 p HC A03/MF A01 CSCL 03B G3/91 N78-24024 Unclas 17687

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MAY 1978

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MARTIAN CANYONS AND AFRICAN RIFTS:

STRUCTURAL COMPARISONS AND IMPLICATIONS

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ABSTRACT

The resistant parts of the canyon walls of the martian rift complex Valles Marineris have been used to infer an earlier, less eroded reconstruction of the major troughs. The individual canyons were then compared with individual rifts of East Africa. When measured in units of planetary radius, martian canyons show a distribution of lengths nearly identical to those in Africa, both for individual rifts and for compound rift systems. A common mechanism which scales with planetary radius is suggested. Martian canyons are significantly wider than African rifts. This is consistent with the long-standing idea that rift width is related to crustal thickness: most evidence favors a crust on Mars at least 50% thicker than that of Africa. The overall pattern of the rift systems of Africa and Mars are quite different in that the African systems are composed of numerous small faults with highly variable trend. On Mars the trends are less variable; individual scarps are straighter for longer than on Earth. This is probably due to the difference in tectonic histories of the two planets: the complex history of the Earth and the resulting complicated basement structures influence the development of new rifts. The basement and lithosphere of Mars are inferred to be simple, reflecting a relatively inactive tectonic history prior to the formation of the canyonlands.

INTRODUCTION

The intermediate geologic evolution of Mars proceeded to the point where terrestrial type crustal uplifts, shield volcanoes and associated rifting began to modify a largely Moon-like surface (Frey and Lowman, 1978; Frey, 1977a). Detailed characterization of these incipient plate tectonic structures of Mars is important to our understanding of the relation between martian and terrestrial geologic styles and evolutionary development. This paper presents a comparison between the rift-type features of the Valles Marineris (Mars) and those of East Africa (Earth).

The Valles Marineris is generally considered a martian rift valley or rift system. Sharp (1973) first described the complex of canyons viewed by Mariner 9; a more recent discussion of the physiography of the troughs based on early Viking imagery is provided by Blasius et al. (1977). Hartmann (1973) compared the Valles Marineris with the Red Sea, and Wood and Head (1977) have presented a general comparison of the martian rift system with a similar sized Venusian Trough (Malin and Saunders, 1977) and with well known terrestrial rift systems. Carr (1974) and Hartmann (1973) showed that the major fractures of the Valles Marineris were the largest of a series aligned radially to the crustal uplift near Tharsis, but detailed study of the structural trends indicates at least two major episodes of crustal flexure are responsible for the present-day canyons (Frey, 1977b,c; see also Masson, 1977).

Because the martian canyon complex is a rift system, composed of a number of individual canyons or troughs, comparison with large-scale terrestrial rift systems (e.g., the Eastern Rift of Africa) is appropriate. Alternatively, the dimensions and structures of the individual martian canyons could be considered along with those of individual rifts in Africa (e.g., the Albert Rift of the

South Gregory Rift). This latter approach is first adopted here; discussion of the overall systems of canyons on Mars and rifts in Africa is considered in the second half of the paper.

THE MARTIAN CANYONS

Detailed descriptions of the martian canyons can be found in Blasius et al. (1977). In general the individual troughs are several hundred kilometers long and up to 150 kilometers wide, merging into a complex central region near $73^{O}W$, $10^{O}S$ (Melas Chasma). Canyons are occasionally separated by inter-canyon ridges, as in Ius and Coprates. Most are connected but Hebes and Juventae Chasma are isolated features to the north of the general Valles Marineris complex. Gangis Chasma is connected to the rest of the troughs through the chaotic, highly dissected terrain of Capri Chasma (which is not discussed below).

For meaningful comparison with the well studied rifts of East Africa, individual canyons must be clearly delineated and measurements of their dimensions accurately made. Such measurements are difficult because of the highly eroded nature of the canyon walls. Fluvial activity, mass wasting, scarp retreat and repeated downfaulting have all contributed to widening the troughs (Sharp, 1973; Blasius et al., 1977). This modification has obscured the original trends of the canyons and confused interpretation of the canyon boundaries.

As described elsewhere, portions of nearly all the canyon walls exist which seem much less eroded than their surroundings (Frey, 1977b). These occur as resistant ridges and cliffs, the latter appearing as wedge-like projections remaining behind as the wall on either side was eroded back from the canyon interior. Figure 1A is a map of some of the main resistant points described in detail elsewhere (Frey, 1977c). In the context of this paper the intercanyon

RESISTANT POINTS IN COPRATES (MC-18)

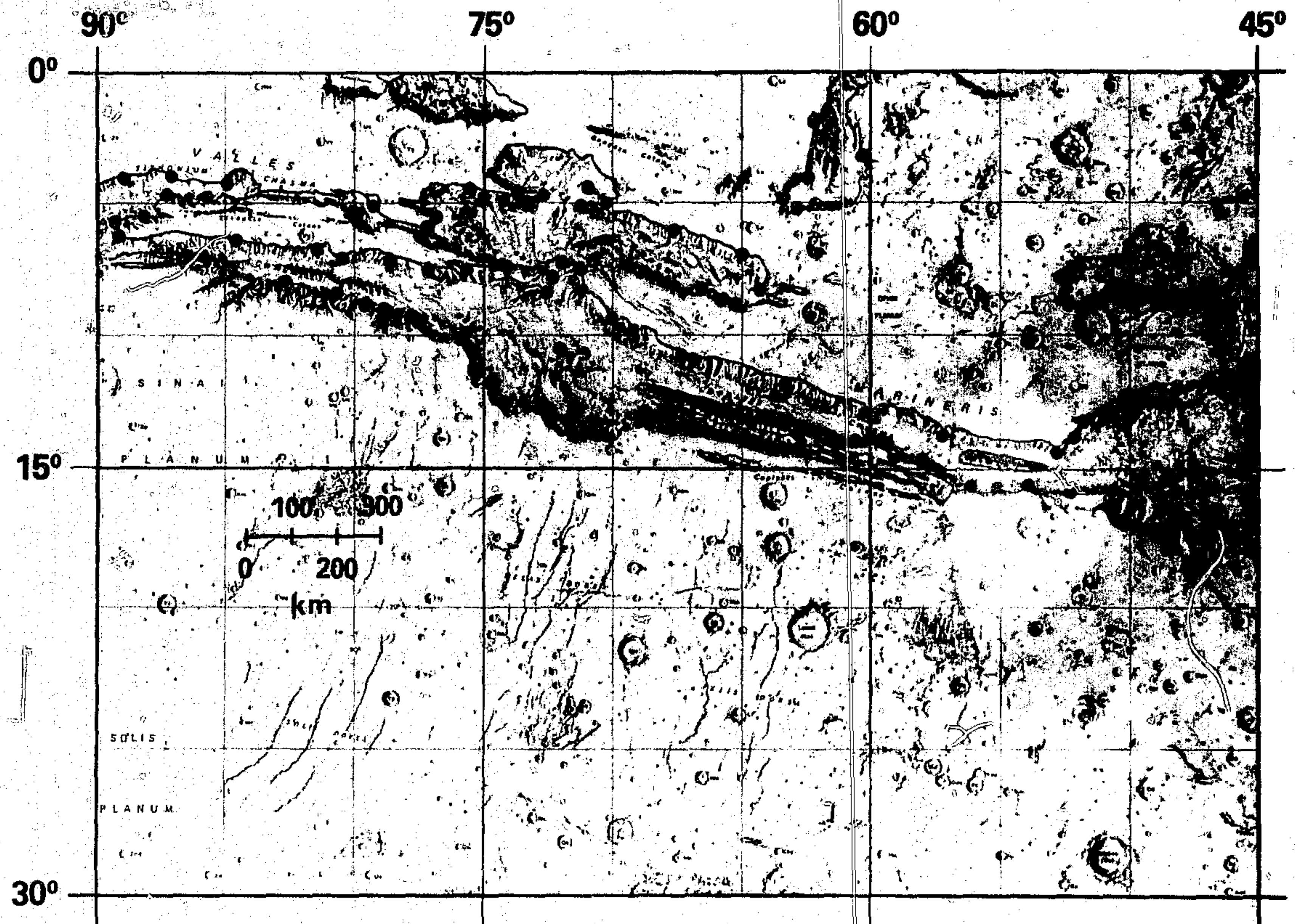
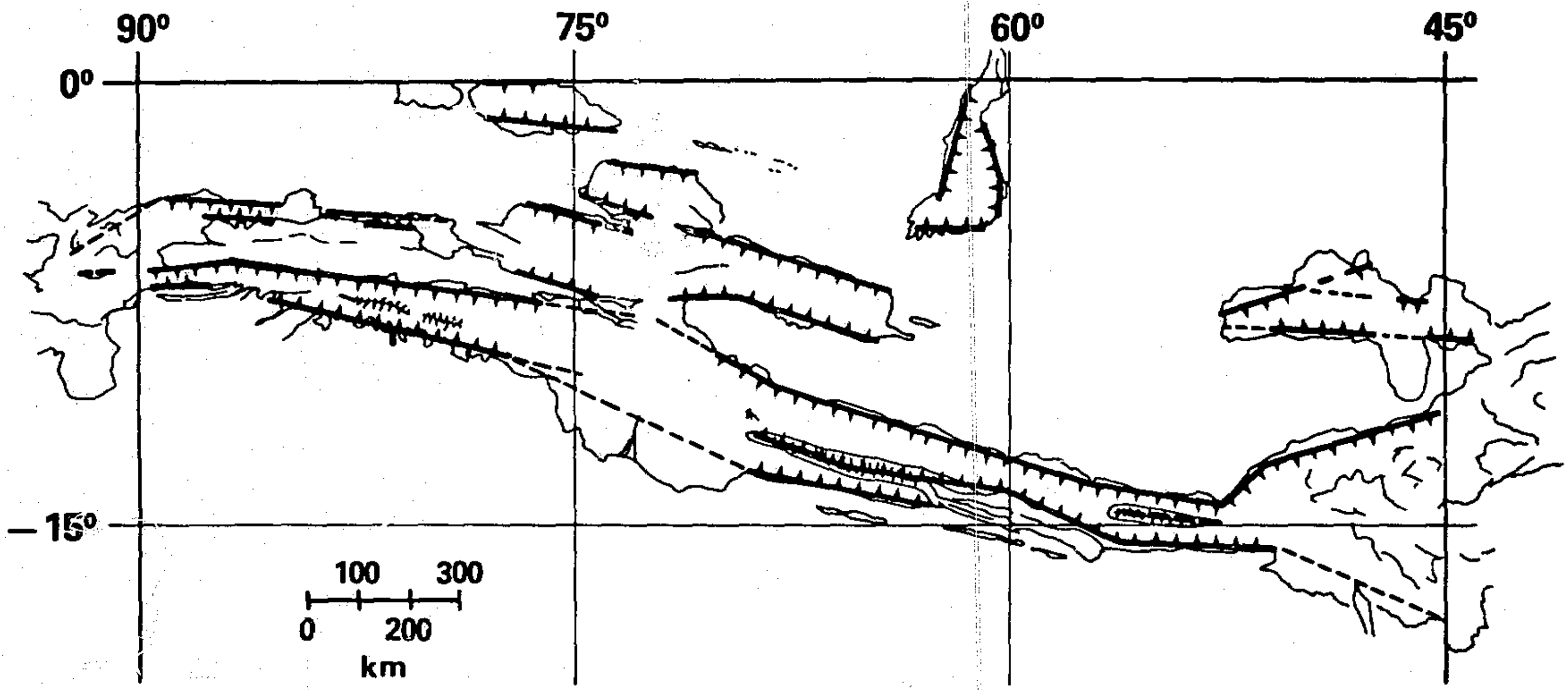


FIGURE 1 A

FIGURE 1B



CANYON WALLS INFERRED FROM RESISTANT POINTS ridge in Ius and Coprates may be considered resistant portions of the canyon walls. The places marked in Figure 1A should not be thought of as pristine remnants of the original walls, but rather as a closer approximation to the original scarps which formed the individual troughs than are the present walls.

To a first approximation a fault trace is roughly linear. Linear trends in the resistant points of Figure 1A may therefore represent an approximation to the master faults forming the original canyon scarps. It is possible to roughly reconstruct the earlier walls of the troughs with such linear trends. One inferred reconstruction is shown in Figure 1B. Teeth point down into the canyons. Solid lines indicate the most obvious trends in resistant points and therefore those most likely to mark the earlier walls. Less certain locations are indicated by dashed lines. This "uneroded" representation should be treated with some suspicion: it almost certainly does <u>not</u> correspond to the <u>original</u> configuration of the walls of the canyons. Rather it is only a closer approximation to those walls. In particular, widths of troughs measured from reconstructions like Figure 1B are only upper limits to the true original width (see below). This approximation has one important advantage: it allows a more confident distinction of individual canyons and measurement of their dimensions than is possible when working with the eroded canyon walls seen today. For example, there is good reason to treat the eastern and northwestern parts of Ophir Chasma as distinct canyons. Likewise Candor Chasma is probably a separate trough from Ophir Chasma and Ius is distinct from Melas. These separations are more easily made using the reconstruction of Figure 1B. Individual martian canyons may now be compared directly with the individual rifts of East Africa.

CANYON AND RIFT DIMENSIONS

Lengths and widths of individual martian canyons and individual rifts in East Africa were measured in the same way. Figure 2 presents sketch maps of East Africa (Figures 2A, B, C) and the Valles Marineris (Figure 2D), on which codes designate the individual features considered. The maps for East Africa are derived from maps found in King (1970) and Illies (1968). Figure 2D was based on the reconstruction shown in Figure 1B. Length measurements are straightforward and are indicated by the long bar running through each canyon or rift. Single measurements suffice here, although some bias is introduced in the decision as to where one rift ends and another begins. It is for this reason that all measurements were made on the same type of map, rather than adopting values for African rifts from the literature. Some error may also exist where straight lines were used to represent the total lengths of features such as Lake Tanganyika (LT) or Luangua (L) whose trends deviate noticeably from straight lines. The measurements made are therefore indicated on the sketch maps of Figure 2.

Many African rifts vary in width along their lengths. Bounding faults are sometimes arranged en echelon or are composed of a series of separate faults of different trend. It is not always obvious which faults should be taken as the bounding scarp, and where widths should be measured. In some cases, graben-within-graben exist. The northern part of the Kenya Rift (here, the North Gregory Rift = NG) is such a feature. Martian canyons also change in width along their lengths. Ius (I) is a good example. West Coprates (WC) and East Ophir (EO) open trumpet-like where they join other canyons. This type of widening can also be seen in Africa at the southern end of Lake Rukwa (LRu) and the northern end of Ethiopia (E). Therefore numerous measurements were made along each rift or canyon and the average and range of values recorded for each. Figure 2 shows the location of these measurements as lines oriented perpendicular to the strike of each canyon or rift.

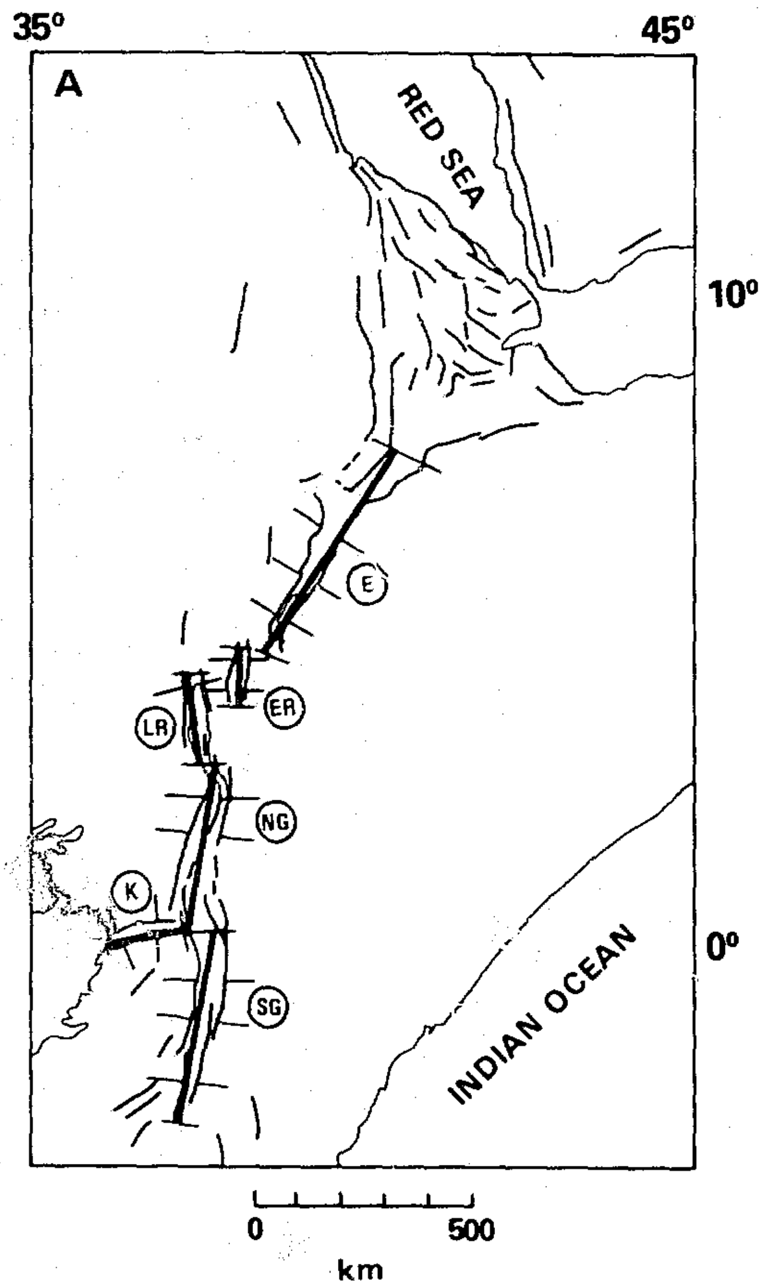


FIGURE 2 A

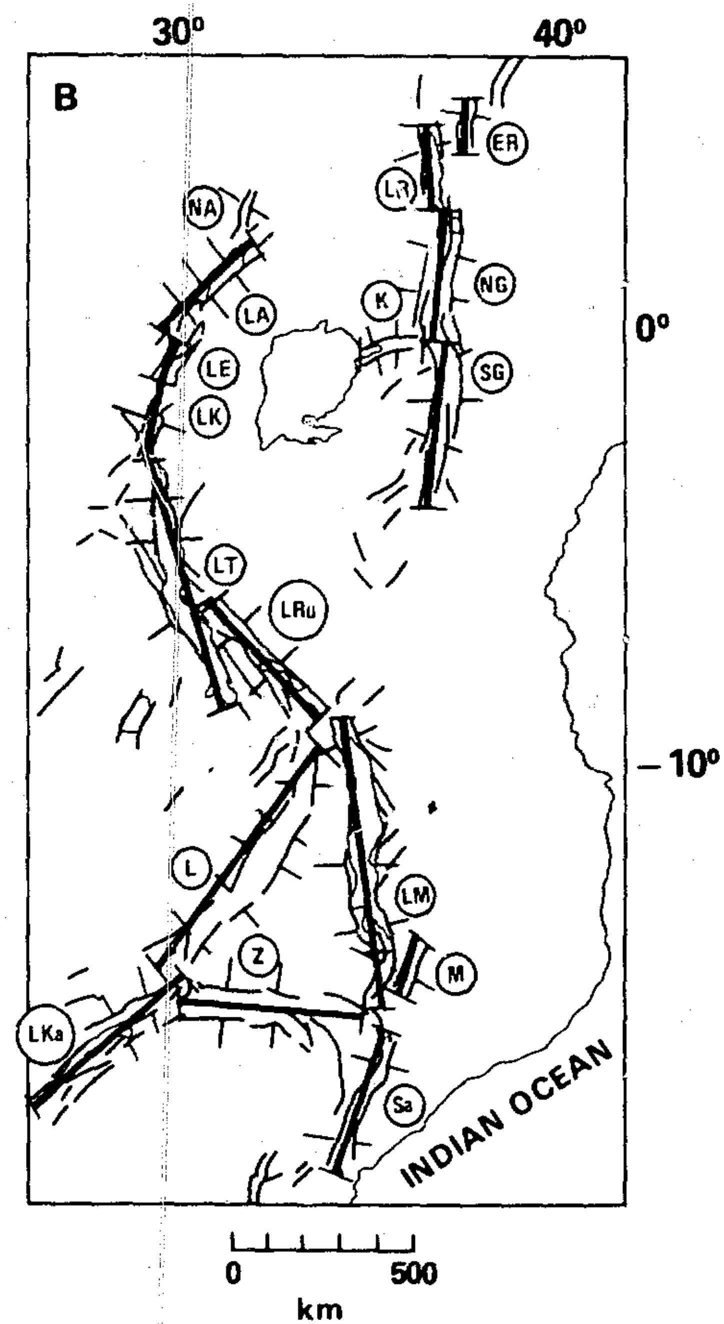
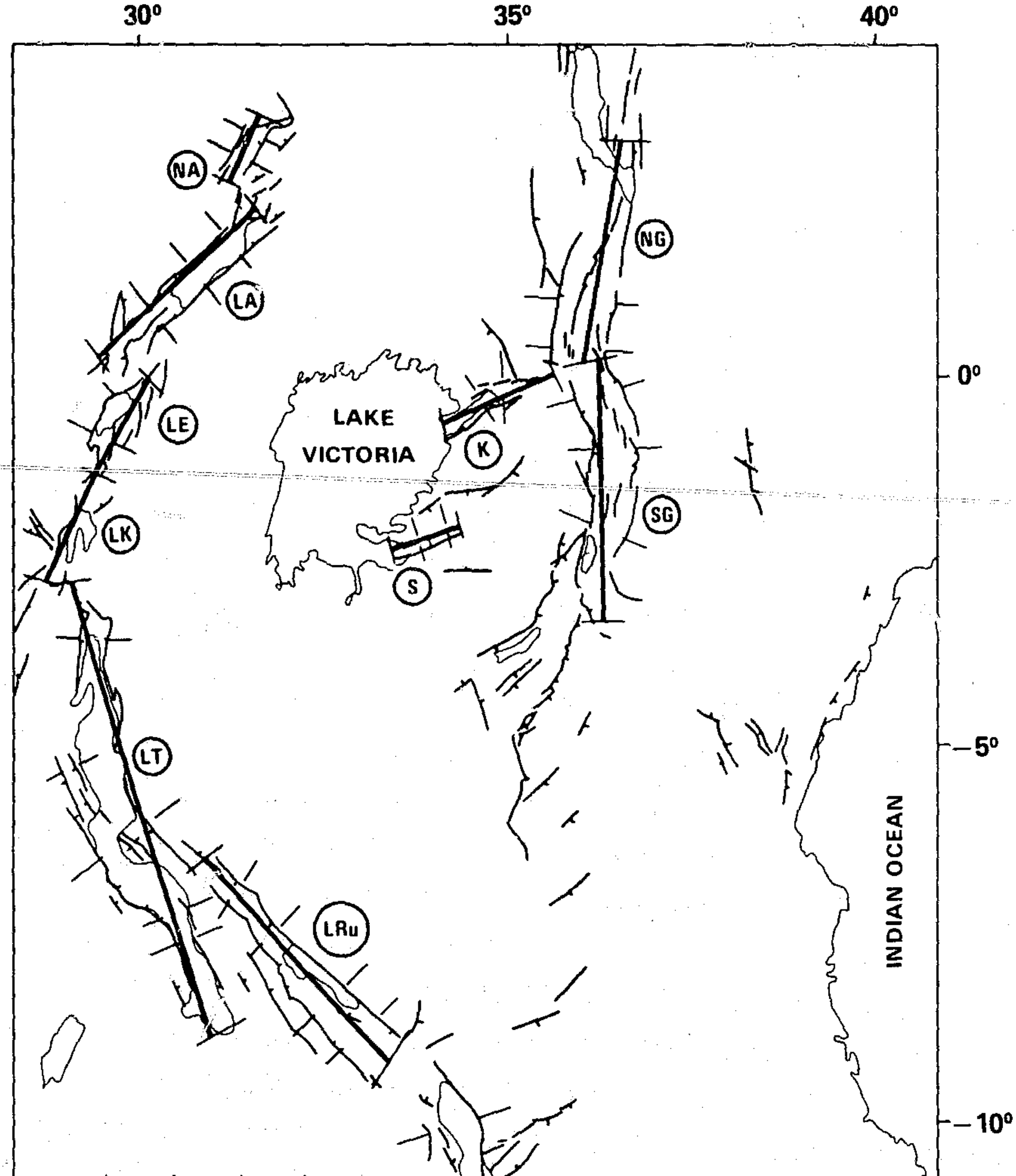
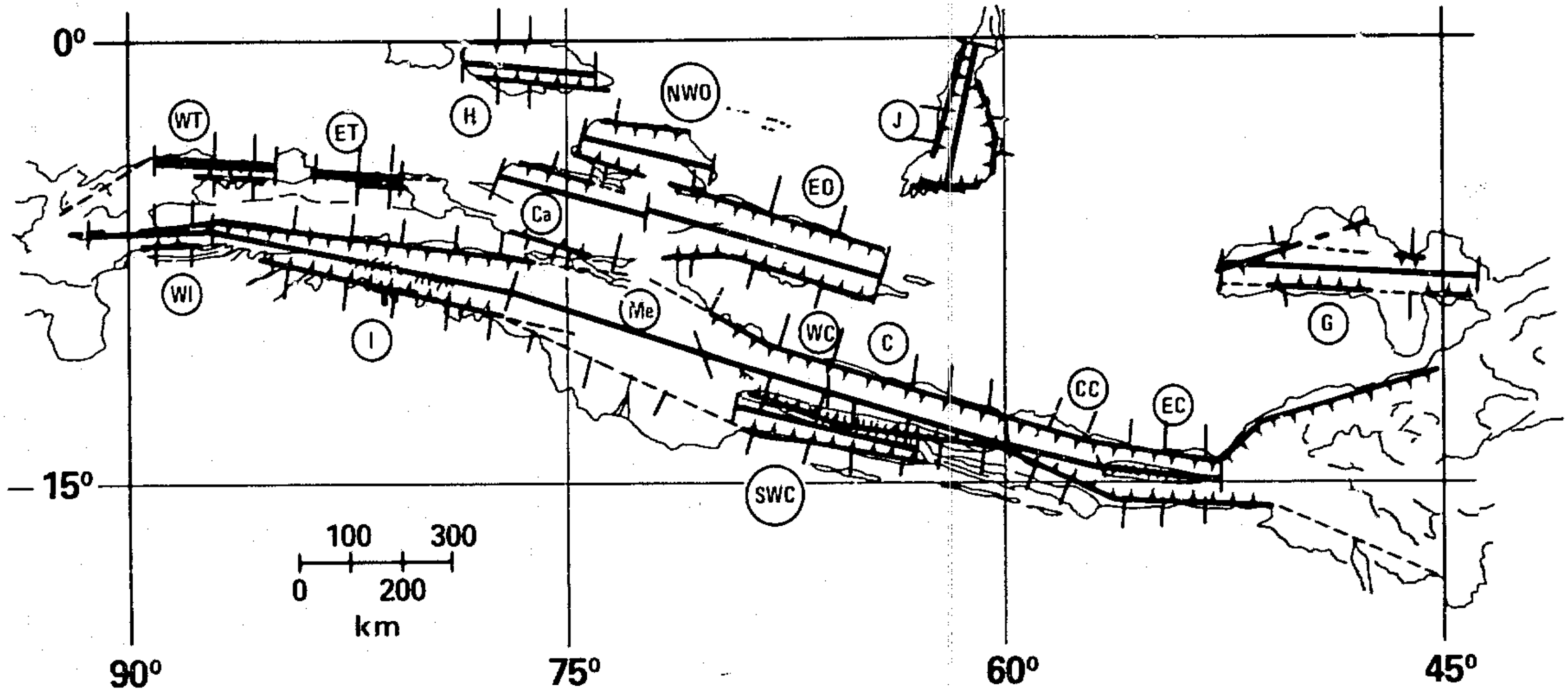


FIGURE 2 B



30°
35°
40°
NA
LA
LE
LK
LT
LRu
NG
SG
K
S
LAKE
VICTORIA
INDIAN OCEAN
0°
–5°
–10°
0
100
200
300
km

FIGURE 2 c



0°
-15°
90°
75°
60°
45°
WT
ET
H
NWO
J
ED
Ca
G
WI
I
Me
WC
C
CC
EC
SWC
100
300
0
200
km

FIGURE 2 D

TABLE I

LENGTHS AND WIDTHS OF AFRICAN RIFTS

RIFT	SYMBOL	MAP	LENGTHS MEASURED	L/R	WIDTHS MEASURED	W/R	RANGE	
Ethiopia	E	A	537 km	.084	43 km	.007	52	30
E. Rudolf	ER	A,B	114	.023	31	.005	37	26
L. Rudolf	LR	A,B	216	.034	50	.008	52	48
N. Gregory	NG	A,B,C	359	.056	74	.012	86	52
S. Gregory	SG	A,B,C	427	.067	60	.009	70	37
Kavirondo	K	B	178	.028	31	.005	35	26
Speke Gulf	S	C	107	.017	14	.002	14	14
Nile Albert	NA	B,C	116	.018	34	.005	37	31
L. Albert	LA	B,C	343	.053	44	.007	52	33
L. Edward	LE	C	163	.026	37	.006	--	--
L. Kivu	LK	B	203	.032	48	.008	--	--
L. Tanganyika	LT	B,C	724	.114	50	.008	70	33
L. Rukwa	LRu	B,C	426	.067	62	.010	95	37
Luangua	L	B	764	.120	68	.011	92	52
L. Kariba	LKa	B	568	.089	72	.011	92	44
Zambesi	Z	B	514	.081	87	.014	87	87
Sabi	Sa	B	416	.065	31	.005	35	26
Mozambique	M	B	156	.024	35	.005	--	--
L. Malawi	LM	B	653	.102	69	.011	82	39

TABLE II

LENGTHS AND WIDTHS OF MARTIAN CANYONS

CANYON	SYMBOL	MAP	LENGTHS MEASURED	L/R	WIDTHS AVERAGE	W/R	Range	
Hebes	H	M	269 km	.079	81 km	.024	83	79
W. Tithonius	WT	M	246	.072	33	.010	33	33
E. Tithonius	ET	M	169	.050	15	.004	17	13
Candor	Ca	M	311	.092	141	.042	142	139
NW Ophir	NWO	M	269	.079	86	.025	--	--
E. Ophir	EO	M	489	.144	113	.033	132	103
Juventae	J	M	295	.087	104	.031	119	89
Gangis	G	M	519	.153	73	.021	76	69
W. Ius	WI	M	256	.075	37	.011	40	33
Ius	I	M	609	.179	93	.027	112	69
Melas	Me	M	408	.120	166	.049	185	139
SW Coprates	SWC	M	376	.111	53	.016	69	43
W. Coprates	WC	M	266	.078	105	.031	106	103
Coprates	C	M	379	.112	84	.025	93	73
C. Coprates	CC	M	194	.057	78	.023	83	73
E. Coprates	EC	M	243	.072	95	.028	99	89

Some degree of internal consistency should be provided by the common measurement procedure used on similar maps. An internal check of the maps and measurement procedure is provided by the overlap seen in Figures 2B, C, and D. Where measured on more than one map, length values differed by less than 25 km and widths by less than 5 km- each less than 10% of the measurement and each less than the bin size used in the histograms below.

TABLE IIIa

LENGTHS OF COMPOUND AFRICAN RIFTS

RIFT SYSTEM	SYMBOL	LENGTH	L/R	RIFTS
Kenya	E-1	787 km	.12	NG, SG
Gregory	E-2	1002	.16	NG, SG, LR
E. Rift	E-3	1539	.24	NG, SG, LR, E
W. Rift A	E-4	1433	.22	LA, LE, LK, LT
W. Rift B	E-5	1859	.29	LA, LE, LK, LT, LRu
W. Rift C	E-6	2512	.39	LA, LE, LK, LT, LRu, LM
W. Rift D	E-7	2028	.46	LA, LE, LK, LT, LRu, LM, Sa
Kariba-Luangua	E-8	1332	.21	LKa, L
African	E-9	4467	.70	NG, SG, LR, E, LA, LE, LK, LT, LRu, LM Sa

TABLE IIIb

LENGTHS OF COMPOUND MARTIAN CANYONS

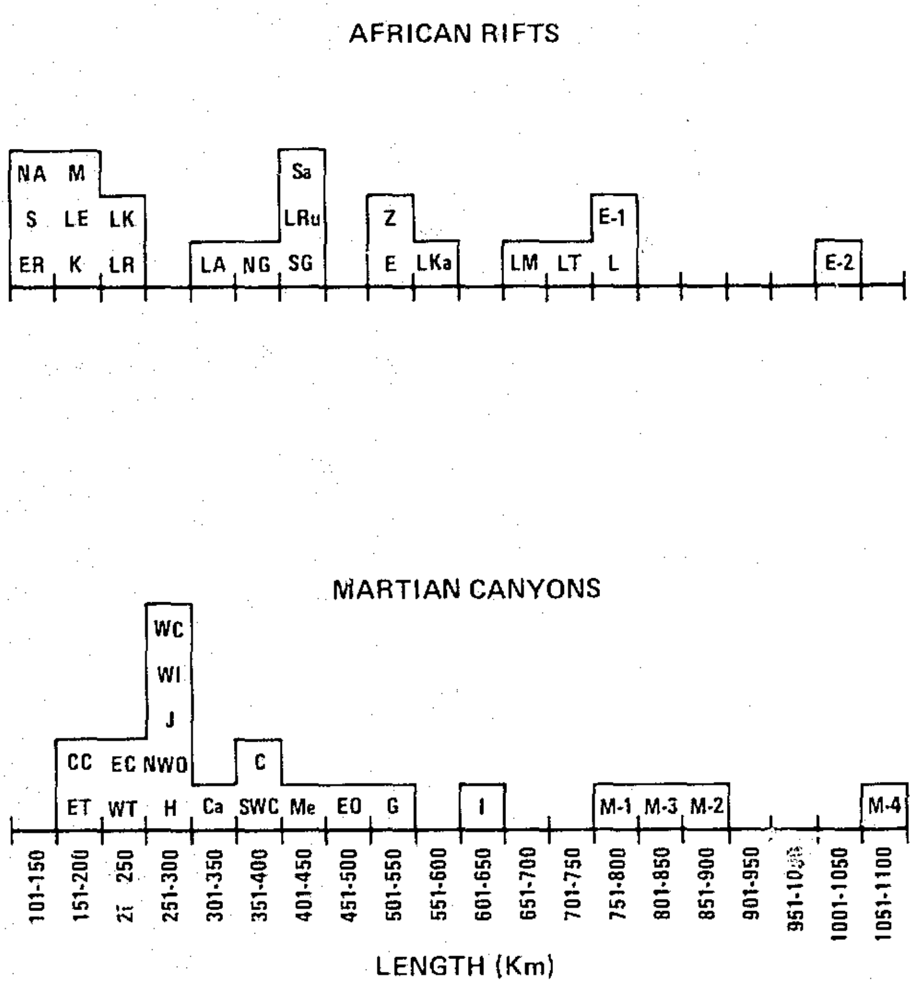
CANYON SYSTEM	SYMBOL	LENGTH	L/R	CANYONS
Candor-Ophir	M-1	800 km	.24	Ca, EO
Ius System	M-2	865	.26	WI, I
W-C Coprates	M-3	839	.25	WC, C, CC
Coprates System	M-4	1082	.32	WC, C, CC, EC
Ius-Coprates	M-5	2099	.62	I, Me, WC, C, CC, EC
Valles Marineris	M-6	2355	.69	WI, I, Me, WC, C, CC, EC

The results for the African rifts are presented in Table I. This and its companion, Table II for the martian canyons, display a designation for the rift, the code used to identify the canyon or rift on the sketch maps, and the map on which the feature may be found (A, B, C refer to Figure 2A, B, C respectively; M refers to Figure 2D). Next follows the measured length in kilometers and the length divided by planetary radius. Measured widths (in kilometers) and widths divided by planetary radius are next. The last two columns give the maximum and minimum widths measured for that feature. Tables IIIa and IIIb list the lengths of compound systems in Africa and on Mars respectively; that is, rifts which join together to form larger more or less continuous structures. For example, the North and South Gregory rifts (NG, SG) combine to form the Kenya rift, designated E-1 in Table IIIa, and the combination of the Candor-East Ophir canyons is shown as M-1 in Table IIIb. These larger systems will be discussed later.

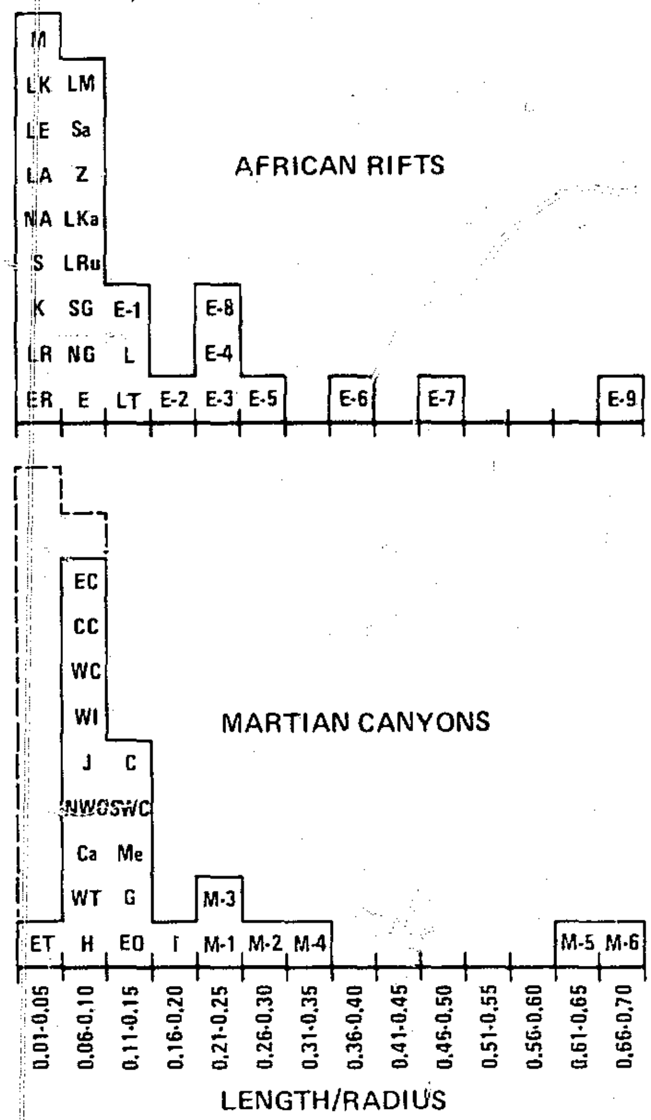
Simple inspection of the "Measured Lengths" columns indicates that both terrestrial rifts in Africa and martian canyons span a similar range in lengths. Perhaps more important than the actual dimensions is a relative measure, listed as "L/R". This indicates the scale of the rift or canyon in units of planetary radius. This column thus measures the feature in terms of the size of the respective planet on which it has formed. Figure 3 presents the data in histogram form. Figure 3A is for absolute lengths (kilometers) and Figure 3B shows the distribution in units of planetary radius. Several points are obvious from these figures:

(a) In units of planetary radius, both terrestrial rifts of Africa and martian canyons are small, generally less than 0.15R, where R is the radius of the planet. The largest measured rift in Africa is Luangua (L); its length is 764 km or 0.12R. The largest canyon of the Valles Marineris, as indicated by Figures 1B and 2D, is Ius (I) at 609 km or 0.18.

MEASURED LENGTH AND LENGTH/RADIUS



A



B

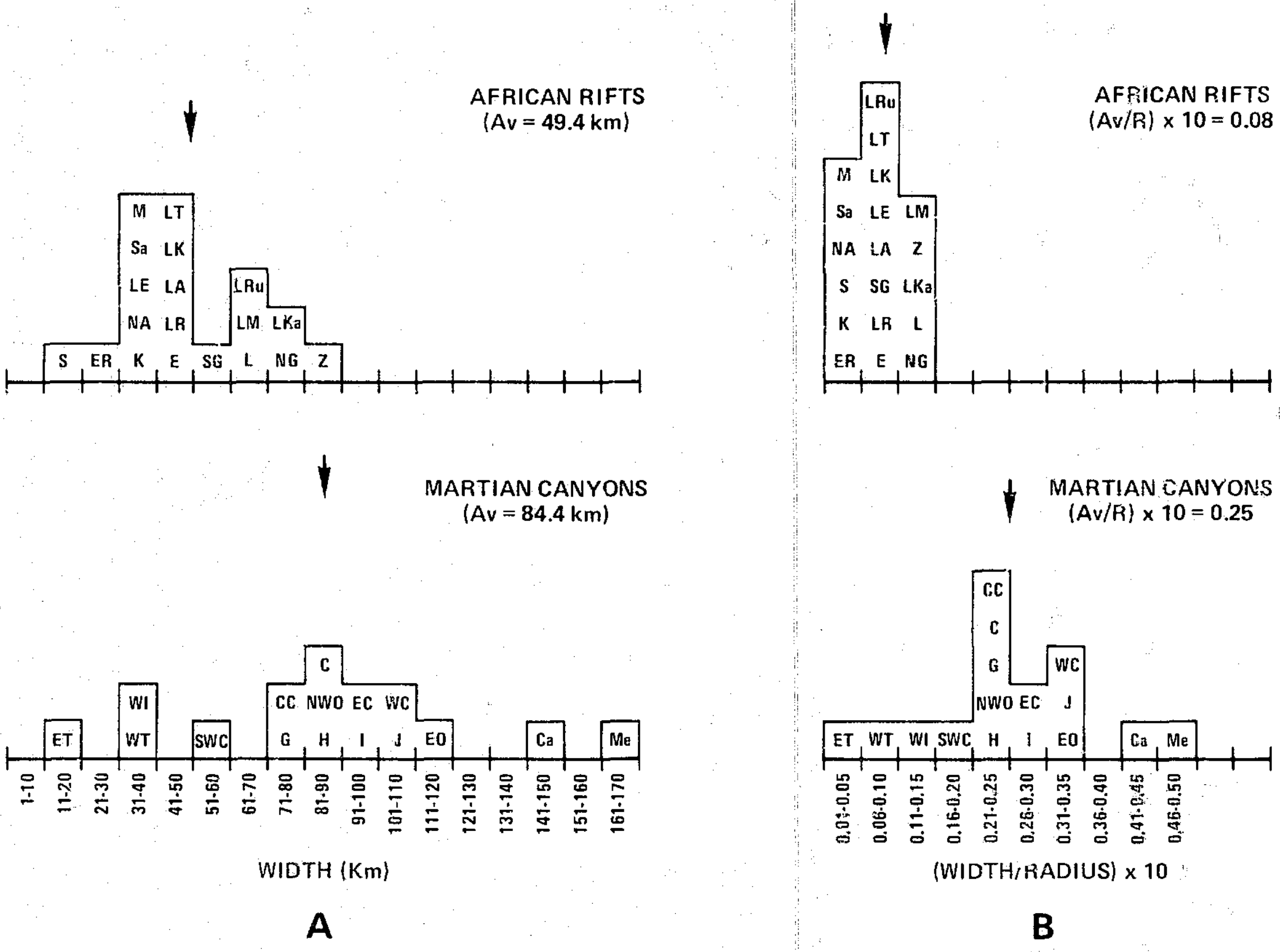
(b) Rift systems, shown in Figure 3 as E-1, 2, 3, etc., and M-1, 2... can be quite large, commonly longer than 0.25R or a quarter of the planetary radius.

(c) Both martian canyons and terrestrial African rifts show remarkably similar distributions in L/R. This is true not only for the individual rifts but for compound systems as well. Individual martian canyons are neither unusually large nor unusually small compared with terrestrial rifts, in units of the planetary radius.

(d) What appears as an empty bin in the martian canyons for L/R = 0.01 to 0.05 is due to exclusion of a possibly related feature, the catena, that parallel the main troughs of the Valles Marineris (see Figure 1A). These pits and chains of depressions have been described by Sharp (1973) and Blasius et al. (1977). Their exact relationship with the main troughs is unclear, but the characteristic lengths of these features is exactly in the range L = (0.01-0.05) $R_{♂}$. The inclusion of these structures would fill in the histogram as shown by the dashed lines.

While martian canyons are similar in length to the African rifts, they are significantly <u>wider</u> than those terrestrial features. Figure 4 shows histograms for widths and width divided by planetary radius. From Figure 4A it is clear that, measured in kilometers, martian canyons average about 84 km wide and African rifts are about 49 km in width. In units of planetary radius, the difference is even more pronounced. For convenience Figure 4B is plotted in units of (W/R) x 10 along the bottom scales. Martian canyons are three times wider than African rifts in terms of the radius of the planet.

MEASURED WIDTH AND (WIDTH/RADIUS) x 10

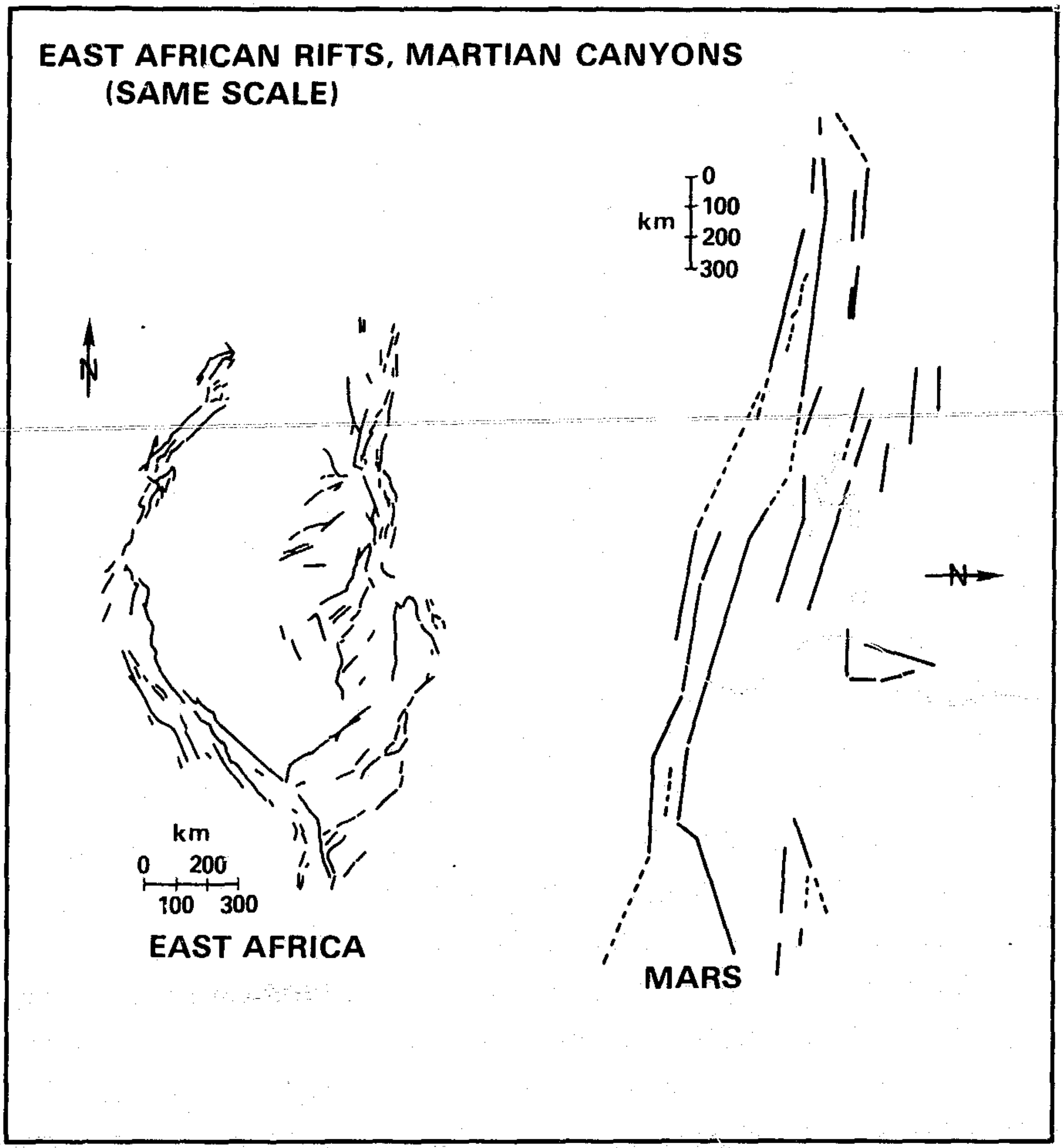


Note that is not simply a consequence of a few very wide canyons. Removal of Melas (Me) and Candor (Ca) canyons (the two widest on Mars) from the averaging process decreases the mean width to only 75 km, which is still, in absolute units, 50% wider than the African average.

Although not displayed here in histogram form, where measured the martian canyons are generally deeper than terrestrial rifts. When allowance is made for erosion of rift shoulders and volcanic filling of African featues, typical throws of the major faults is 2-3 km (Beloussov, 1969; Menard, 1973). Measurements in the central portion of the Valles Marineris indicate that depths of 6 km are common (Malin, 1977, as referenced in Blasius et al., 1977).

STRUCTURAL CHARACTERISTICS

In East Africa numerous small rifts trend along a roughly common direction, forming a continuous rift system. One example is the Western Rift. From Nile Albert and Lake Albert in the north through Lake Edward and Lake Kivu, and south into the large Lake Tanganyika and Lake Rukwa rifts, individual troughs link into a complex, continuous, curving system more than 1800 km long (see Figure 2C). This in turn connects further south into the reactivated Luangua and Lake Malawi rifts which continue even further south. The Valles Marineris on Mars has a similar characteristic continuity. West Ius and Ius join at Melas Chasma with the Coprates rifts (West Coprates, Coprates, Central Coprates and East Coprates), as shown in Figure 2D. Comparison of these larger system characteristics of the martian canyons and African rifts is found in Figure 5A and 5B. The first shows the Valles Marineris (rotated 90^{0}) and the East African Rift system near Lake Victoria (deleted from the sketch map) at the same scale in kilometers. Figure 5B reproduces the Valles Marineris and East African Rifts in units of planetary radius.



EAST AFRICAN RIFTS, MARTIAN CANYONS
(SAME SCALE)
N
km
0
200
100
300
EAST AFRICA
0
100
200
300
km
N
MARS

FIGURE 5 A

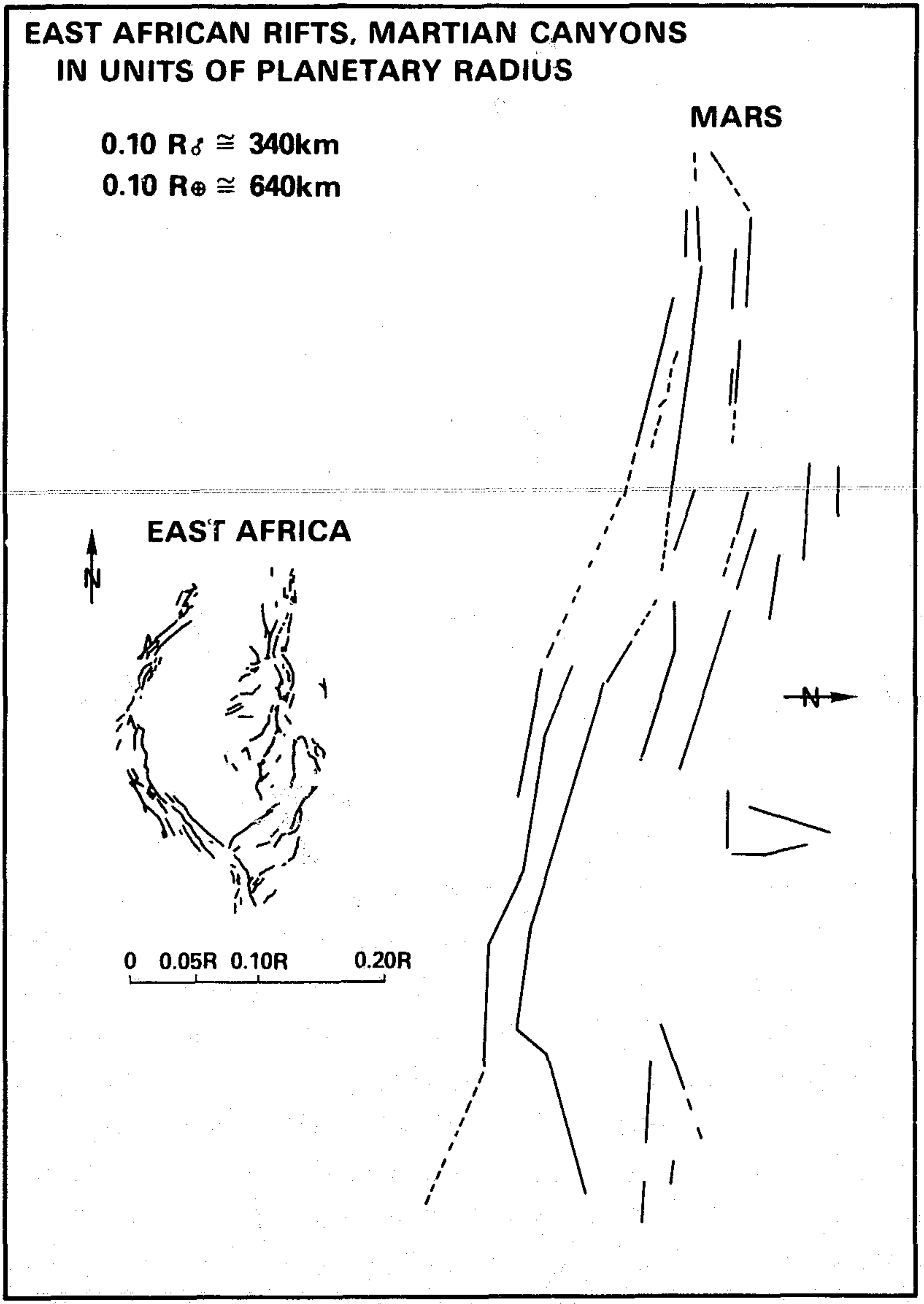

EAST AFRICAN RIFTS, MARTIAN CANYONS
IN UNITS OF PLANETARY RADIUS
MARS
0.10 R♂ ≅ 340km
0.10 R⊕ ≅ 640km
EAST AFRICA
N
N
0 0.05R 0.10R 0.20R

FIGURE 5 B

Several of the observations made above are clearly shown in these Figures. Individual rifts or canyons (i.e., segments of the larger systems described above) have comparable L/R for both planets (compare East Ophir on Mars with Lake Tanganyika in Africa, or the martian Melas with the terrestrial Luangua; locations shown in Figure 2). But martian rifts are clearly wider, either in absolute units (km) or in units of the planetary radius. The rift systems have total comparable lengths: The Western Rift of Africa (W Rift-B, E-5, Table IIIa) is roughly 1860 km long, similar in length to the Ius-Coprates system (M-5 of Table IIIb). It is clear from Figure 5 that the African systems are composed of numerous small segments with significant variation in trend. The martian system is much less variable, more nearly constant in trend.

As King (1970) has pointed out, while the Eastern Rift (for example) in Africa (North and South Gregory, Lake Rudolf and Ethiopia) maintains a rough North-South orientation, individual rifts seldom are found with this trend. Individual rifts themselves are often composed of numerous faults which vary in trend within the rift, although parallelism of the bounding faults is generally maintained. This is true elsewhere on Earth. For example, the Rhine Graben master faults maintain a close parallelism while changing direction along their 300 km length (Illies, 1968). The overall pattern in Africa is disjointed and complex on the small scale but with a persistant direction on the large scale. The lengths of individual faults which maintain a single orientation in Africa are generally less than 200 km, often less than 100 km.

On Mars the situation is quite different. Bounding scarps inferred from resistant points are straighter for longer distances than in Africa. Typical lengths in Ius or Coprates are 400 km or longer for the major scarps. There is, of course, considerable uncertainty in the location of the "reconstructed" wal and the pattern suggested in Figure 1B is undoubtably too simple. But complication of that Figure by drawing shorter lengths cannot match the complexity observed in Africa. The martian system is simpler and more coherent over a much greater distance than are the rift system of Africa.

DISCUSSION

The close similarity of the length/radius histograms (Figure 3) for both Mars and East Africa is striking. A common process which scales with planetary radius is suggested. Further testing of this important conclusion may be possible when further radar observations better delineate the full dimensions of the Venusian Trough (Malin and Saunders, 1977). This suggestion of a common mechanism that scales with the planetary radius has important implications for the comparative evolutionary studies of these two planets.

Unfortunately the observation of a similar distribution in L/R implies nothing directly about the mechanism of rifting itself. On the Earth rifts are produced by extension related to crustal uplifts; these uplifts are probably an isostatic response to injection of low density mantle material into the lithosphere (Burke and Whiteman, 1973; Menard, 1973; Bhattacharji and Koide, 1975). In the Kenya Rift multiple episodes of crustal flexure occurred, each accompanied by volcanism and fracturing (Baker and Wohlenberg, 1971; Baker et al., 1972). The driving mechanism behind the injection of the low density mantle material is unknown, but is perhaps related to mantle plumes (Dewey and Burke, 1973) or to convective motions in the upper mantle. A similar sequence of events may have occurred on Mars, whose thermal history included mantle convection (Toksöz and Hsui, 1977). The relation of the canyons to crustal warping is not clear, however, in the case of Mars. The Valles Marineris system lies along the flank of the Tharsis Uplfit, not along the crest as is generally the case on Earth. A smaller topographic bulge to the east of Tharsis is more nearly centered on the canyons (Christensen, 1975; Blasius et al., 1977). Furthermore, the temporal relations between the fracturing at the Valles Marineris and the culmination of the Tharsis Uplift are unknown, although it is generally accepted that the two are related (Hartmann, 1973; Carr, 1974). There is evidence for orthogonal structural trends in the Valles Marineris; these may indicate earlier crustal warping near Thaumasia predated the uplift at Tharsis (Frey, 1977b,c; see also Masson, 1977). Improved determinations of the topography and temporal relations of these features are required to pin down the evolutionary history of the martian canyons.

Other mechanisms of extensional fracturing have been proposed. For example, an increase in planetary radius (Solomon and Chaiken, 1976; Toksoz and Hsui, 1977). The common L/R distributions for Mars and the Earth do not rule out such models, but is suggestive that common processes were operative on both planets. It is also not clear why planetary expansion should produce the single rift system seen on Mars. That is, it becomes necessary to explain why other parts of the planet were not equally stressed. Perhaps improved numerical modeling of the thermal histories will clarify this situation.

The difference in the W/R histograms for Mars and the African rifts is important, perhaps reflecting basic differences in lithospheric properties. Terrestrial continental rifts have a rather restricted range in widths (Beloussov, 1969; see Figure 3A); these widths are roughly equivalent to the thickness of the crust (see, e.g., Illies, 1968). Expectation that this should be the case goes back to the early experiments of Cloos (see, e.g., Freund, 1967; Holmes, 1965), who demonstrated that rift valley structures could be produced in layers of wet clay under which a balloon was inflated (simulating the uplift of the crust). In those experiments the width of the graben formed was equal to the thickness of the layer of clay. Mechanically it is the lithosphere that is the brittle layer of the

Earth, but below rift valleys this thins to near crustal depths (Girdler et al, 1969, Figure 6; Baker and Wohlenberg, 1971, Figure 7), presumably due to the emplacement of the low density mantle mass responsible for the crustal swell and subsequent injection of such material into the lithosphere.

Wood and Head (1977) suggest that the great width of the martian canyons is consistent with terrestrial experience, reflecting a thicker crust for Mars. Canyon widths measured here average ~84 km wide; these are upper limits due to uncertainty in the location of the reconstructed walls. Because the resistant points on which that reconstruction was based are themselves likely to have been somewhat eroded, the actual widths of the original canyons could have been narrower. The range in measured widths (Table II) for Mars reveals the narrower parts of the canyons may have widths 10 km or so less than the average. Even these should be an upper limit for the narrow part of the canyon walls. It does not seem possible, however, that the average value for the martian canyons can be decreased to agree with that of the African average of 49 km. We estimate 65-75 km as a lower limit to the average canyon width on Mars. (75 km is the average that results from deletion of the two widest and most eroded canyons, as described above.)

Thus the average width of the canyons of Mars is significantly greater than the average width of the African rifts. If the rift width is indeed related to crustal (or lithosphere) thickness, then the crust of Mars in the vicinity of the Valles Marineris should be some 50% thicker than that of Africa. The Tharsis Ridge was described as a region of thicker than average crust by Phillips et al. (1973) in a broad-scale Bouguer analysis of Mariner 9 tracking data. Their model assumed a mean crustal thickness of 50 km but was relatively insensitive to the assumed density contrast between crust and mantle. In a later paper Phillips and Saunders (1975) found that the Tharsis uplift was only partly compensated at shallow depth ($\lesssim$ 150 km), assuming a uniform crustal density. Their Figure 2, a typical case, shows little isostatic deviation for the central Valles Marineris. This may have important consequences for the temporal relations between the formation of the canyonlands and the Tharsis Uplift. Most crustal modeling has concentrated on the Tharsis region, but an isopach map derived in conjunction with a possible detection of a single seismic event by the Viking II lander (into which a large number of assumption have been fed) shows a crustal thickness of 50-60 km in the vicinity of the Valles Marineris (Bills and Ferrari, 1977, as referenced in Anderson et al., 1977). Considering the uncertainty in both this determination and in the measured widths of the martian canyons, the agreement is intriguing. The conclusion of Wood and Head (1977) that wider rifts on Mars may reflect greater crustal thickness on that planet is supported. The measurements presented here may provide improved constraints on the thermal evolution of Mars if the time of formation of the canyonlands can be accurately determined.

A possible application of this common effect can be seen for the Earth. The evolution of the Kenya Rift proceeded in rather discrete episodes of uplifting with accompanying volcanism and fracturing (Baker and Wohlenberg, 1971). A broad, asymmetrical trough was formed first about 15 million years ago. Later, narrow graben developed within the main trough. If the widths of graben are related to crustal thickness (as suggested by experience on two planets) then crustal thinning must have occurred in Kenya <u>during</u> the development of the rift. This is to be expected if hot, low density mantle material is being wedged into the lithosphere to the base of the crust. Gravity profiles (Baker and Wohlenberg, 1971; Girdler et al., 1969) and the presence of central volcanism during the last stages of rifting support this idea. It may therefore be possible to map the thinning of the crust (or lithosphere) in the evolutionary development of graben in Africa.

Important clues about the comparative tectonic history of Earth and Mars result from the comparison of structural trends in the martian and African rift systems (Figure 5). The complex nature of the East African rift systems reflects basement control (King, 1970; Beloussov, 1969). African tectonic history has been complex, resulting in a heterogeneous mosaic of blocks, folds and belts (Clifford, 1970) stretching back into Archaen times. These ancient basement structures have influenced the more recent faulting, leading to the complex, variable-trend pattern observed. This is true elsewhere on the Earth (e.g., Illies, 1968). Conversely, the simple, trend-preserving pattern observed in the Valles Marineris suggests a relatively homogeneous crust and lithosphere. By implication the tectonic history of the martian lithosphere has been relatively simple. That is, there are few basement structures to influence the faulting in the Valles Marineris because the history of that basement has been relatively inactive. This may explain the simple structural grains seen in the canyonlands with their apparent radial association with two major crustal uplifts (Frey, 1977c). That repeated downfaulting along the existing canyon walls is observed (Blasius et al., 1977) is also consistent with the idea of relatively simple basement structures.

This view is consistent with the absence of plate tectonic structures of a collisional variety (fold belts, andesitic volcanoes) on Mars (see Wood and Head, 1977; Frey, 1977c), and the convincing evidence for lithospheric immobility (Carr, 1974) which has produced the enormous volcanic piles of the Tharsis Montes and Olympus Mons. The Valles Marineris represent the first major fracturing of, and graben formation in, the martian lithosphere, which until this period of tectonic activity was relatively simpler if a good deal thicker than that of the Earth. Because the peak of the thermal pulse has passed (Toksöz and Hsui, 1977; Johnston and Toksöz, 1977) further rift valley development is unlikely. The evolution of this planet ended with <u>incipient</u> plate tectonic activity (Frey and Lowman, 1978).

CONCLUSIONS

The resistant portions of the canyon walls of the martian rift complex can be used to infer an earlier, less eroded reconstruction of the troughs. The individual canyons indicated by this reconstruction can be measured and compared with individual rifts of East Africa. In units of planetary radius, martian canyons show a distribution of lengths nearly identical to those in Africa but which are significantly wider than terrestrial rifts. The first observation suggests a common mechanism of rifting which scales with planetary radius, but of itself says nothing about the nature of that mechanism. Processes similar to those producing rifts on the Earth (extension resulting from crustal uplift due to low density mantle material injected into the lithosphere) seem likely for Mars, but the relation of the martian fractures to crustal swells is not clear.

The greater width of the martian canyons is consistent with the long-held view that rift width is related to crustal (or lithospheric) thickness. The martian crust may have been 50% thicker (at the time of formation of the canyons) than the present African crust. The simple trends and long individual scarp lengths seen in the martian rift system indicate a simple, relatively inactive tectonic history prior to the fracturing that formed the Valles Marineris. By contrast, the lithosphere of the Earth is a complex layer whose history and present basement structures produce complicated fault patterns in the African rifts. The results shown here are consistent with an incipient plate tectonics evolutionary development for Mars, and agree with previous determinations that Mars has never experienced large scale lithospheric mobility of the plate tectonics variety.

ACKNOWLEDGEMENTS

It is a pleasure to thank Paul Lowman and Chuck Wood for their encouragement and discussions of rift valleys and canyons, and especially Barbara Lueders for her excellent typing of this manuscript on short notice. This research was supported by NASA Grant NGL 21-002-033.

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BIBLIOGRAPHIC DATA SHEET

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM-79548		

4. Title and Subtitle	5. Report Date
MARTIAN CANYONS AND AFRICAN RIFTS: STRUCTURAL COMPARISONS AND IMPLICATIONS	May 1978
	6. Performing Organization Code
7. Author(s) Herbert Frey	8. Performing Organization Report No.
9. Performing Organization Name and Address Geophysics Branch, Code 922, Goddard Space Flight Center, Greenbelt, MD 20771 and, Astronomy Program, University of Maryland, College Park, MD 20742	10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address same as above	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

Submitted to ICARUS

16. Abstract

The resistant parts of the canyon walls of the martian rift complex Valles Marineris have been used to infer an earlier, less eroded reconstruction of the major troughs. The individual canyons were then compared with individual rifts of East Africa. When measured in units of planetary radius, martian canyons show a distribution of lengths nearly identical to those in Africa, both for individual rifts and for compound rift systems. A common mechanism which scales with planetary radius is suggested. Martian canyons are significantly wider than African rifts. This is consistent with the long-standing idea that rift width is related to crustal thickness: most evidence favors a crust on Mars at least 50% thicker than that of Africa. The overall pattern of the rift systems of Africa and Mars are quite different in that the African systems are composed of numerous small faults with highly variable trend. On Mars the trends are less variable; individual scarps are straighter for longer than on Earth. This is probably due to the difference in tectonic histories of the two planets: the complex history of the Earth and the resulting complicated basement structures influence the development of new rifts. The basement and lithosphere of Mars are inferred to be simple, reflecting a relatively inactive tectonic history prior to the formation of the canyonlands.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Rifts, Lithospheric Evolution, Crustal Evolution	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
U	U		

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

GSFC 25-44 (10/77)