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The Eratosthenes-Strabo Nile Map. Is It the Earliest Surviving Instance of Spherical Cartography? Did It Supply the 5000 Stades Arc for Eratosthenes' Experiment?

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At the very outset of his account of Egypt, STRABO[1] provides a disarmingly crude, thus hitherto-neglected map of the Nile River all the way from Meroe (c. 17° N. latitude) north to the river's terminus (c. 31° N.). STRABO credits the map to his renowned predecessor in geography, ERATOSTHENES of Cyrene, who was director of the great Library at Alexandria (in the Nile Delta) c. 235–195 B.C. (two centuries before STRABO). ERATOSTHENES is best remembered for his famous determination of C, the Earth's circumference: $C_E = 252{,}000$ stades. (C_E is 1/6 or 17% larger than the actual girth, $C_A = 216{,}000$ stades, where 10 stades = 1 nautical mile. It is convenient also to use units of 100 stades = 1^c = 10 nautical miles; *e.g.*, $C_E = 2520^c$.)[2]

An outline of the Nile Map:

a) From Meroe city to the north tip of Meroe region (a river-bounded area known as "Meroe Island"), north 7^c.

b) From Meroe north to the river's Turn A, 27^c.

c) From Turn A roughly southwest to Turn B (at about the same latitude L as Meroe), 37^c.

d) From Turn B, north to the 2nd (great) Cataract, 53^c.

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[1] STRABO 17.1.2.

[2] That 1 stade = 185 meters (almost exactly 1/10 nautical mile) is well established (see, *e.g.*, *Encyclopaedia Britannica*, 1974, **19**, 728). Nonetheless, some scholars are unwilling to believe that ERATOSTHENES' C_E could be so far in error as 17%; they therefore try to show that his stade was smaller than 185 meters. (*I.e.*, they attack the basic unit of Hellenistic macrometrology, rather than suppose C_E was seriously wrong.) FISCHER's papers (1975a and 1975b) are a recent survey, summing-up, and embodiment of this viewpoint. For a discussion of its flaws, see Appendix B. For a simple and novel physical explanation of C_E's error, see Appendix A or RAWLINS, 1980.

e) From the 2^{nd} Cataract "slightly towards the east" to the 1^{st} Cataract ("the smaller cataract, at Syene" near the Tropic of Cancer), 12^c.
f) From thence to the Mediterranean Sea (the Nile Delta and Alexandria), 53^c.

Upon examining closely the data STRABO exhibits (a–f), one is first struck by the repetition of 53^c, and then by the fact that the pure north/south (N/S) distances (53^c twice, 27^c, 7^c) may be formed from halving 53^c+ successively: 27^c-, (13^c+), 7^c-. This suggests the theory that there is a basic unit U underlying the map and that U must lie within the limits:

$$2 \cdot 26^c \tfrac{1}{2} = 53^c < \mathrm{U} < 53^c \tfrac{1}{2}. \tag{1}$$

The halving procedure reminds us that primitive trigonometry tables used intervals of halvings of 30° (presumably from the ease of computation and contruction). A chord table believed to be of Hellenistic origin[3] uses an interval of $30°/(2^2) = 7°\frac{1}{2}$. We quickly realize that, since the N/S distance Alexandria–Syene (which is very nearly equal to U, as we see from item f, above) is $7°+$, then the basic Nile Map unit U is $\frac{1}{4}$ of 30°. Thus, using C = 360°, we have

$$\mathrm{U} = 7° \tfrac{1}{2} = \mathrm{C}/48. \tag{2}$$

From inequality 1 and equation 2, we see that the N/S distances on the Nile Map have provided us a close constraint on the Earth-circumference $\mathrm{C_N}$ underlying the Map:

$$2544^c < \mathrm{C_N} < 2568^c. \tag{3}$$

Since the Map is based upon halvings, the obvious choice in the brief range inequality 3 allows is

$$\mathrm{C_N} = 10^c \cdot 2^8 = 2560^c. \tag{4}$$

From this (and C = 360°), we discern a Map scale (and thus a size of the Earth) which is not quite the same as the well known, traditional one of ERATOSTHENES ($2520^c/360°$ or $7^c/1°$)[4]:

$$\text{Nile Map scale} = 2560^c/360° = 64^c/9° = 7\overset{c}{.}1111/1° \tag{5}$$

on a great circle. Combining with equation 2, we have (also great circle)[5]

$$\mathrm{U} = 53^c 1/3 = 160^c/3. \tag{6}$$

Now, with this necessary groundwork laid, we return to the Map itself and correct an obvious corruption;[6] since it was well known[7] that the L-difference

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[3] NEUGEBAUER, 1975, pp. 1132, 299–300.

[4] *E.g.*, STRABO 2.5.34.

[5] Eq. 6 applies for latitude L; for longitude, use instead $\mathrm{U} = (160^c/3) \cos \mathrm{L}$.

[6] Another corruption is the L-gap between Turns A and B, which is too large by a factor of about $2\frac{1}{2}$—probably due in part to a very early distortion of the fact (true within $\frac{1}{4}°$) that Turn B has about the same L as MRNT, into: same as Meroe city. (Note that, if leg iii is halved, Alexandria and Meroe end up on the same meridian, which agrees with tradition; STRABO 1.4.2.)

[7] STRABO 1.4.2, 2.1.3, NEUGEBAUER, 1975, p. 1313, PLINY 2. 183–184.

of Alexandria and Syene nearly equalled that between Syene and Meroe, then items (d) and (e) above certainly should be restored as: The direct distance from Turn B to the 1st Cataract (near Syene) is a vector 53^c north and 12^c east, the latter component being largely due to the obtuse turn (unlike the acute turns A and B), near the 2nd Cataract, somewhat towards the east (from approximately northward, to: approximately northeastward along the stretch between the two Cataracts).

Having reconstructed the original Map, we now encapsulate its description of the Nile's course, in the simple terms established:

(i) Meroe city to N. tip Meroe region (MRNT), U/8 north
(ii) MRNT to Turn A, $U/2 - U/8 = 3U/8$ north
(iii) Turn A to Turn B, vector U/2 south and U/2 west
(iv) Turn B to 2nd Cataract, 3U/4 north
(v) Cataract 2 to Cataract 1, vector U/4 north and U/4 east
(vi) Cataract 1 to Nile Delta, U north.

Taking the 1st Cataract as the Map's zero point ($x = 0$, $y = 0$) at N. latitude $L = 24°$ (accurate in fact to c. 1′—and a 24° angle was constructable by the ancients), east longitude $E \equiv 0$, we set out in Table 1 the coordinates established, some hints of which survive independently.[8]

Table 1. Latitudes L and Longitudes E of Reconstructed Nile Map

# Place	(actual L)	L	y	E	x
1. Nile Delta	$(30°–31°\frac{1}{2})$	$31°\frac{1}{2}$	$+53^c\frac{1}{3}$	$0°$	0^c
2. Cataract 1	(24° 01′)	24°	0^c	$0°$	0^c
3. Cataract 2	(22°–)	$22°\frac{1}{8}$	$-13^c\frac{1}{3}$	$-1°\frac{7}{8}$	$-12^c.35+$
4. Turn B	(17° 59′)	$16°\frac{1}{2}$	$-53^c\frac{1}{3}$	$-1°\frac{7}{8}$	$-12^c.78$
5. Turn A	(19° 31′)	$20°\frac{1}{4}$	$-26^c\frac{2}{3}$	$+1°\frac{7}{8}$	$+12^c.51$
6. MRNT	(17° 41′)	$17°\frac{7}{16}$	$-46^c\frac{2}{3}$	$+1°\frac{7}{8}$	$+12^c.72$
7. Meroe city	(16° 58′)	$16°\frac{1}{2}$	$-53^c\frac{1}{3}$	$+1°\frac{7}{8}$	$+12^c.78$

In the Table, y represents the distance north of the 24° N. parallel, and x is the great-circle distance east of the meridian through the 1st Cataract. (Negative y signifies south of 24° N. And negative x signifies west of the 1st Cataract meridian —same convention of sign for longitude E.) The relation between L and y is a simple exercise in use of the Map scale (equation 5), but since E is not measured on a great circle, we must also take that into account when relating x and E:

$$x = \frac{64^c}{9°} E \cos L. \tag{7}$$

[8] Pharos Island, in the harbor of Alexandria, is listed at $31°\frac{1}{2}$; and Elephantine Island off Syene, at 24°, in some editions of the *Geographical Directory* (4.5.76 and 70, respectively); obliquity 24° popular (NEUGEBAUER, 1975, p. 733); as for Meroe and $16°\frac{1}{2}$, see footnote 15.

Use of this equation and equations 2 and 5 suffices to convert the data set out previously (as items i through vi) into Table 1.

We are now in a position to check the distances (between points) of Table 1 against those given in STRABO's account (provided at the outset, items a through f). It is immediately apparent that, if interpoint Table 1 x–y data are rounded to the nearest 1^c (the precision expressed in STRABO's report), the agreement with STRABO's figures is exact in all 6 cases.

The diagonal distance AB from Turn A to Turn B is found from either a simple Cartesian approximation

$$AB \doteq [(x_5 - x_4)^2 + (y_5 - y_4)^2]^{\frac{1}{2}} = 36^c\!.75 \tag{8}$$

or rigorous spherical trigonometry

$$\cos AB = \sin L_4 \sin L_5 + \cos L_4 \cos L_5 \cos (E_4 - E_5) = 0.995933. \tag{9}$$

From equations 5 and 9,

$$AB = 5^\circ\!.169 = 36^c\!.76. \tag{10}$$

Thus, since STRABO has distance AB $= 37^c$ (item c, above), our check-confirmation is complete.

From the ERATOSTHENES-STRABO Nile Map, what do we learn about geography before 200 B.C.?

1. At that early epoch, maps were already being executed in true spherical coordinates (even while using the most primitive angular measure). We note parenthetically that:

a) Nothing in the Map requires use of degrees.

b) All angles L and E of Table 1 may be constructed by ruler and compass (not possible for a degree)—via techniques well known to the ancients.[9]

2. Whoever converted the original (spherical geography) version of the Nile Map from pure angles into stades used a scale (equations 5) based upon taking the circumference of the Earth as $C_N = 2560^c$ (equation 4) which is almost 19% higher than the actual size ($C_A = 2160^c = 216{,}000$ stades), however

a) C_N is only 1% off the value ($C_{GJ} = 2592^c$) one would obtain via either of 2 easy methods (Appendix A) which determine the curvature of the sea, an approach the foundation of which ERATOSTHENES explicitly rejected.[10] (C_{GJ} is 20% higher than actual C_A.)

b) C_N is within 2% of C_E, the value which ERATOSTHENES reported as the result of his own famous experiment, which of course should have yielded the true value, $C_A = 2160^c$.

We conclude therefore that:

A. Spherical coordinates and trigonometry are indicated to be at least as ancient as ERATOSTHENES.[11]

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[9] NEUGEBAUER, 1975, p. 22.

[10] STRABO 1.3.11.

[11] However, from item 1b, above, we see that trigonometry is not absolutely required. (Equation 9 may be replaced by equation 8.) But at the least, we must recognize

B. Since neither the Map's C ($C_N = 2560^c$) nor its U ($7^c\frac{1}{2}$)[12] are ERATOSTHENES' values (2520^c and $7^\circ 1/5$, respectively), the Nile Map pre-dates him.[13]

Conclusion B triggers our astonished awareness that, in the Nile Map, we have at last stumbled upon the probable solution to one of the oldest disputes[14] in the history of geography: from where did ERATOSTHENES obtain his famous Alexandria-Syene arc of 5000 stades (50^c)?

It has previously long been asserted[15] that the 50^c arc was measured by direct land-survey, *e.g.*, royal pacers: some formidable feet, given the Nile's sinuosity as well as the lethal desert to either side, which must be crossed by the bee-line traveller.

However, if ERATOSTHENES' 50^c was (as now seems highly likely) merely a rough rounding of the 53^c of the Nile Map's item f (above), then we realize two crucial points:

a) The roughness of most of the Map (compare to reality) rules out its being based on an accurate *land*-survey.

b) The Map (and thus the 53^c in question) is instead based upon (largely[16] rough-rounded) *astronomical* data.

Nonetheless, since it evidently came to ERATOSTHENES' attention long after being transformed into a stades format, the Nile Map was *understood by him* to provide for the Alexandria-Syene meridian arc a fairly reliable value based on land survey, c. 5000 stades (50^c), upon which he reared his legendary C-measurement experiment,[17] which found that this terrestrial 50^c arc corresponded to a

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that the construction of the Nile Map and the construction of a table of sines would require similar techniques. (Moreover, the existence of trigonometry is consistent with the agreement of ERATOSTHENES' northern latitudes with values calculated for a 12-minute-interval climata table, using spherical trigonometry. See also footnote 15, below.)

[12] Note well that Z, the real zenith distance of the Sun at noon on the Summer Solstice at Alexandria, was then $7^\circ\frac{1}{2} = C/48$, in contrast to the $7^\circ.2 = C/50$ that ERATOSTHENES obtained by using a gnomon, which automatically shaves 16′ off a zenith distance. CLEOMEDES 1.10 is quite clear that ERATOSTHENES' Z was taken via gnomon. Incidentally, does the contrast of POSIDONIUS' C/48 with ERATOSTHENES' C/50 in this passage provide a corrupt glimmer of a long ago disagreement regarding Z? Regardless, the Nile Map's basic unit U is a glaring hint that Alexandrian astronomers other than ERATOSTHENES were well aware that the correct Z was in fact $7^\circ\frac{1}{2}$, not $7^\circ 1/5$.

[13] Borrowing from his precedessors does not seem to have been beyond him. (See, *e.g.*, note 18, below.) As a matter of fact, he was suspected of worse (BUNBURY, 1883, **1**, 588 notes 2 and 3, and DICKS, 1960, p. 145; also PLINY, Preface 22, and STRABO 1.2.2, 2.1.40–41).

[14] See, *e.g.*, NEUGEBAUER, 1975, p. 653, vs. FISCHER, 1975a, 1975b.

[15] *E.g.*, MARTIANUS CAPELLA 598, FISCHER, 1975a, 1975b. Does the former's reference to "official surveyors in the employ of King Ptolemy" go back to the construction of the Nile Map and/or to PTOLEMY II's prefect PHILO (PLINY 37.108)? The arc spoken of is Syene-*Meroe* (not Alexandria), and we know that PHILO reported solar observations made at Meroe (STRABO 2.1.20), a corrupt version of which (*Alm.* 2.6) is consistent with Meroe $L = 16^\circ\frac{1}{2}$ in Table 1 (using spherical trigonometry of *Alm.* 1.14) *as* are the shadow-data of *Alm.* 2.6.

[16] But see footnote 12, above.

[17] Described by CLEOMEDES 1.10 and MARTIANUS CAPELLA 596–598.

C/50 (astronomical arc 7°.2) difference of altitudes of the sun at noon on the Summer Solstice. Thus

$$C = 50^c(1/50)^{-1} = 2500^c. \tag{11}$$

This outcome he later rounded (for divisibility) to a distance PLINY attributes[18] to PYTHAGORAS (2520^c = PYTHAGORAS' distance from Sun to Moon), the well-known "ERATOSTHENES" value, 252,000 stades = 2520^c. (I have not seen this remarkable identity previously cited. It might be added that 2520, being the lowest common denominator of all the integers from 1 to 10, is PYTHAGORAS' sort of number.)

Therefore, while ERATOSTHENES thought he was following his famous method by comparing his astronomical arc (7°1/5) to a terrestrial arc (5000 stades) to determine C, he was in reality instead unwittingly comparing his astronomical arc to someone else's disguised astronomical arc!—namely the 50^c which he had gotten from the Nile Map (rounding 53^c to 50^c)[19], unaware that this was simply an astronomical angle[20] fleshed out (long before the Map came into his hands) into stades via equation 5, *i.e.*, presuming a C equal to 2560^c (C_N). Thus ERATOSTHENES' choice of the Nile Map as the "survey" upon which to found his experiment for determining C, inevitably incorporated a C of 2560^c; he was therefore bound to deduce something near that value (after roundings) at the end of the experiment. In brief, he was reasoning in a circle—and one of pre-determined circumference, at that.

In view of C_N's remarkably close (1%) resemblance to the value C_{GJ} based on sea-curvature (20% higher than the actual C_A)—especially striking in the context of the other standard ancient C's exactly equalling the other sea-curvature-based C (17% below actual C_A; see Appendix A)—it is difficult to resist the thought that ERATOSTHENES ended up unknowingly endorsing a C-value obtained by *the very means he thought he was rejecting*,[21] instead of the (theoretically[22] superior) method he is remembered for.

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[18] PLINY 2.83; the distance from Sun to Moon = 252,000 stades, from Earth to Moon, half that, and from Sun to zodiac, the sum of these 2 distances.

[19] A possible vestige of justification for rounding 53^c to 50^c may be found in CLEOMEDES 1.10: 300 stadia of vagueness in the position of the subsolar point in the vicinity of Syene. (True for the Tropic, but in ERATOSTHENES' era the Tropic was never within 150 stadia of Syene. Presumably he read of this, but neither observed nor understood it.)

[20] See above, footnote 12 and also footnote 15.

[21] Above, footnote 10.

[22] ERATOSTHENES method of measuring C (equation 11 and footnote 17, above) is, in theory, superior to the sea-curvature methods (Appendix A), because atmospheric refraction will have a negligible effect upon the outcome—which therefore should be almost exactly equal to the actual circumference of the Earth $C_A = 2160^c$ ($\neq 2520^c = C_E$). However, *in practice*: whereas taking sea-curvature data is easy and local, carrying out ERATOSTHENES' alleged experiment (see footnotes 15 and 17, above) would have entailed the gargantuan labor of measuring on foot a sizable portion (1/50) of the entire globe!—much of it over desert, if the path was a straight line. We are discovering in this paper that ERATOSTHENES' probably was not up to handling a bother of that magnitude—finding

Appendix A
Methods for Measuring the Earth's Size by Determining the Apparent Curvature of the Sea

The ancients knew that the sea's radius was the same as the Earth's.[23] And the measurement of the sea's apparent curvature was easily within the capabilities of ancient scientists' physical knowledge, mathematics, and instruments.[24]

Any one of three simple techniques could have been used which we shall call sea-curvature methods:

Method G. Measuring the angular dip of the sea-horizon as observed from a known height.[25]

Method J. Determining how far out at sea a lighthouse flame (of known height) is visible at night.[26]

Method S. Finding the time-difference between two sea-horizon sunsets. The first is observed from sea-level and the second, from a known height directly above the point at which the first observation was made.[27]

All three sea-curvature methods will yield seriously erroneous results (the error factor being 6/5 in all three cases),[28] due to the effect of atmospheric refraction on the light observed during the measurements, a systematic influence for which the ancients evidently had no way of correcting quantitatively. By contrast, ERATOSTHENES' method will yield the correct value for C, namely $C_A = 2160^c$.[29] The results of the three sea-curvature methods are, respectively:

$$C_G = (6/5)\, C_A = 2592^c;\ C_J = \text{same} = C_{GJ};\ C_S = C_A/(6/5) = 1800^c.$$

Now, only two C-values are known to have come into wide use in the ancient world: ERATOSTHENES' $C_E = 2520^c$ and POSIDONIUS' $C_P = 1800^c$. Both are 17% off the truth ($C_A = 2160^c$), but the former is only 3% below C_{GJ} (and its likely underlying source, $C_N = 2560^c$, as shown in this paper, is just 1% below C_{GJ}) while the latter is *identical* to C_S. Clearly, the standard ancient C-values are far more consistent with the two values (C_{GJ} and C_S) expected from sea-curvature

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it easier instead just to borrow (see footnote 13, above) what he mistakenly thought was the fruit of someone else's vast labor in measuring the Alexandria-Syene terrestrial arc (namely, that portion of the Nile Map).

[23] See, *e.g.*, STRABO 1.3.11.

[24] For detailed discussion, see RAWLINS, "The Case for Ancient Earth-Measures ... from Sea-Curvature Determinations", in preparation.

[25] RAWLINS, 1980. Appropriate instrument discussed by HERON (NEUGEBAUER, 1975, p. 845, and VAN DER WAERDEN, 1963, p. 104).

[26] Such data are relayed in JOSEPHUS 4.613, and deliberate experimentation is implied in PLINY 2.164.

[27] RAWLINS, 1979. We know that the ancients timed the solar disc rising/setting (CLEOMEDES 2.1) for another purpose.

[28] NEWCOMB, 1906, pp. 198–203.

[29] See footnotes 2 and 22.

methods than with the value (C_A) expected from ERATOSTHENES' method (formerly believed to be the basis of both C_E and C_P; see Appendix B).

Appendix B
Racking the Stade for Erathosthenes

A vast Procrustean literature has grown up and fed on itself, especially in this century, attempting to show serious variability in the stade, always in hopes of forcing ERATOSTHENES' $C_E = 2520^c$ closer to reality (*and* POSIDONIUS' $C_P = 1800^c$ closer to both).

The most common technique is to cite PLINY 12.53, which, typically, is then manipulated to show that ERATOSTHENES' stade = 1/10 Roman mile = 148 meters $\neq$ the standard Greek stade = 1/8 Roman mile = 185 meters. (The international nautical mile is defined as 1852 meters, which is obviously very close to 10 stades.) Unfortunately for this scenario, the full passage in PLINY 12.53 assumes 8 stades = 1 mile. Indeed, PLINY 2.247 explicitly converts $C_E = 252{,}000$ stades to 31,500 miles—again 8 stades = 1 mile.

The most recent promotion for dovetailing C_E and C_A through varying the stade solves this difficulty by simply omitting[30] the 8 stades per mile portions of both of these quotations from PLINY. The author attempts to show[31] that the schoinos was more stable than the stade, and thus that equating ERATOSTHENES' stade with 1/40 schoinos (according to PLINY 12.53) = 1/10 mile may be contrasted with the usual stade = 1/32 schoinos = 1/8 mile. This is utterly contradicted by STRABO,[32] not to mention PLINY 12.53 itself, which says that ERATOSTHENES' schoinos = 5 miles, not the schoinos = 4 miles used to show (above) that 1 stade (1/40 schoinos) = 1/10 mile.

Appendix C
Previous Orthodoxy on Ancient Spherical Geography

The existence in early Greek geography of any mathematically defined map projection is problematic ... The first trace of a general discussion of geographical mapping seems to be a passage in STRABO[33] where he says that the *oikemene* [inhabited world] can be most accurately represented on a colossal globe (as supposedly constructed by CRATES, about 170 B.C.) ten feet in diameter. For the *oikemene*, however, a plane map should do ... [7 feet long] orthogonal network or ... "slightly converging" meridians ... no numerical data are mentioned for these constructions which look like a precursor of the mapping used by MARINUS (about A.D. 100).[34]

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[30] FISCHER, 1975a, p. 10, 1975b, p. 164.

[31] FISCHER, 1975a, p. 10, 1975b, p. 159.

[32] STRABO 7.7.4, 11.11.5 and 17.1.24 (vs. 17.1.3 as used by FISCHER, 1975b, pp. 152–153).

[33] STRABO 2.5.10.

[34] NEUGEBAUER, 1975, p. 735.

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