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ABSTRACT

Time-sharing computer-assisted instructional (CAI) programs employing the APL language are being used in support of introductory earth science laboratory exercises at the State University of New York at Binghamton. Three examples are sufficient to illustrate the variety of applications to which these programs are put. The BRACH program is used in paleontology to demonstrate the natural variations in morphology of a fossil species; SEIS provides an analysis of time-travel relations of seismic waves; and ROTS offers a general purpose rotation program which is helpful in the study of continental drift and paleomagnetism. A time-sharing CAI system is recommended because it allows introductory students to explore exciting fields more thoroughly than otherwise possible and provides the teacher with instructional flexibility. APL is useful because it requires little computer sophistication on the part of the student, offers an accurate program, quickly performs complicated and time-consuming computational operations for the student, and improves his accuracy and his confidence in his ability to learn. (PB)

THE TIME-SHARING COMPUTER  
IN INTRODUCTORY EARTH SCIENCE

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Introduction

Time-sharing computer support for laboratory exercises in introductory earth science courses makes available to the instructor a much wider range of assignments than is otherwise possible, and therefore allows greater flexibility in designing the laboratory program. As a result, the student obtains a deeper exposure to geological principles and processes. The net effect adds to the interest of both instructor and student. The purpose of this report is to describe our use of the time-sharing computer in support of introductory earth-science laboratory exercises. We first discuss some of the guidelines we adopted in designing our computer programs, and secondly we describe some examples of programs relating to various branches of earth science. We have found that the use of the time-sharing language APL\* will handle correspondence

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has allowed us to follow our guidelines to our complete satisfaction. We strongly endorse the time-sharing approach since it allows immediate response, contributing to the satisfaction and enthusiasm of the student user and avoiding the time-delay frustrations of the punch-card computer methods.

Philosophical guidelines governing use and design of computer support.

Our principal guideline in integrating the computer into the laboratory exercises is that the maximum amount of the students' time should be devoted to learning about geological principles, not about the principles of computers and computer languages. Using the computer should be made as simple as possible. Furthermore, we resolved that the computer should be used only where it would allow students to explore topics in greater detail than otherwise possible, or to explore old fields in a better way, or to explore completely new fields.

Following our first guideline, we attempt to keep instructions for the use of the computer few and simple. For example, we do not teach a 'primer' course in APL, but give only a few instructions for signing on and signing off the terminal, for calling stored programs, and for entering and correcting data.

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Similarly, the design of the computer program must be as fool-proof as possible, to avoid error messages which might confuse the uninitiated student user. Attention is drawn to a hidden danger in designing simple programs. The danger is that the program will do too much, leaving the student with little to interpret, or with little to think about in a geological sense. Ideally, we believe a program should perform only those operations, particularly mechanical, repetitive, or uninformative calculations, which the student would find unnecessarily complicated and/or time-consuming.

In addition to saving time for the student, a further aim of our computer usage is to improve the accuracy and thereby inspire the confidence of the student in his own results. This should serve to focus the student's attention on the geologic interpretation of his results. What can be more exasperating to a student than to spend a great deal of time and effort obtaining a result by hand, only to find an unreasonable result because of some simple arithmetical error? Compound this frustration with more time spent looking for the error, and perhaps not finding it, and it is easy to understand how the student's interest may waver from the subject matter at hand. Proper use of computer support should alleviate some of these difficulties, making the subject matter more palatable, and even inviting.

With these thoughts in mind, let us look at some examples in which APL time-sharing programs have been

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incorporated into introductory earth-science laboratory exercises. These programs have been used as accessories in a variety of introductory courses in the past few years at the State University of New York at Binghamton. They have been used by faculty both with and without training in APL.

#### Examples of computer usage in introductory earth science

The geological applications of APL are numerous and varied at all levels, in geophysics, geochemistry, petrology, structural geology, and so on. Presented here are three examples relating to different branches of geology at an elementary level, in paleontology, seismology, and continental drift and paleomagnetism. Some of these programs were designed directly for use in the introductory course. Others have evolved indirectly from purely research applications, being first adapted for use in advanced courses, and finally simplified for use in the introductory course.

BRACH. This simple statistical program is designed to be used in a paleontological exercise which demonstrates the natural variations in morphology of a fossil species. The name derives from brachiopoda, a phylum of bilaterally symmetrical clam-like organisms which reached its evolutionary climax during the Paleozoic era, hundreds of millions of years ago. Although introductory students cannot be expected to identify and classify fossils, they can easily

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learn to count corrugations or ribs, to measure dimensions (length, breadth, width), and otherwise to obtain numerical data which can be used to characterize fossil specimens. By calling BRACH, they can obtain the statistical parameters such as mean and standard deviation for their observations quickly and precisely, with a minimum of additional effort. They can be given realistic problems, such as comparing an unknown specimen with a group of known specimens and determining on a statistical basis whether or not the unknown should be classified with the known specimens. Such an exercise draws the student's attention to the physical ornamentation and other morphological variations of fossils and encourages the measurement of as many parameters as can be observed. Through the use of BRACH, the investment of time of the student is shifted away from laborious statistical computations towards making observations, measuring parameters, and making decisions in classification based on statistical information that the student feels he can trust.

SEIS. Variations of this program are used to analyze the travel-time relations of seismic waves, especially of compressional waves. Some of the difficulties in designing seismologic exercises for introductory students is related to the calculation of the travel-time relations. Three equations must be solved to obtain travel-time relations for direct, reflected

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and refracted rays of compressional body waves. The important travel-time relations are as follows, for a simple two-layer case where

- the interface is parallel to the upper surface, i.e. thickness  $d$  of upper layer is constant,
- velocity  $V_1$  of upper layer is less than velocity  $V_2$  of lower layer,
- $x$  is distance along upper surface from source (explosion or earthquake focus) to seismometer,
- $t$  is elapsed time,

$$\text{for the direct ray: } t = \frac{x}{V_1} \quad (1)$$

$$\text{for the reflected ray: } t = \frac{(x^2 + 4d^2)^{1/2}}{V_1} \quad (2)$$

$$\text{for the refracted ray: } t = \frac{x}{V_2} + \frac{2d \cos \theta_c}{V_1} \quad (3)$$

$\theta_c$  is the critical angle for refraction and is obtained from the relationship

$$\sin \theta_c = \frac{V_1}{V_2}$$

Curve (1) is a straight line through the origin; it is asymptotic to the hyperbola (2) and is cut by the straight line (3) which is tangential to the hyperbola. In a physical sense, the point of tangency of (2) and (3) can be interpreted as the distance at which the first refracted ray arrives at the seismometer, and the point of

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Intersection of the two straight lines (1) and (3) is the distance at which the direct and refracted rays arrive simultaneously at the seismometer.

SEIS can be paired off with different laboratory exercises in a variety of ways. For example, the student can be asked to plan the spacing of seismometers for a seismic survey to determine the thickness of a given rock formation. This might be compared with the spacing and arrangement of seismometers necessary for a seismic refraction determination of the thickness of the continental crust of the Earth. Alternatively, the effects of contrast of seismic velocity between two layers can easily be investigated. The use of SEIS allows the student to acquire an intuitive feel for some of the variables of seismic exploration.

Where a portable seismic 'thumper' apparatus is available, SEIS can be used to test the correctness of experimental velocity and thickness determinations by the students. A simple APL plot routine may then be desirable, for the purpose of giving a direct comparison of the travel-time curves of the experiment and of the interpretative 'model'. This allows the student to test, and if necessary to modify his interpretation.

ROTS is a general purpose rotation program which can be used in many geological applications involving rotations. Geologists frequently are required to rotate lines, planes,

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or surfaces in space. In more advanced courses like mineralogy, structural geology, sedimentology, and others, these rotations commonly have been done by using a mathematical projection of a spherical grid, such as a stereographic or similar projection. However, the time required to teach the principles of stereographic projection is too great for an elementary survey course in geology. The use of a computer program such as ROTS is therefore thought to be ideal, in that it allows students to perform complicated rotational maneuvers in the simplest possible way.

One of our favorite examples of the use of ROTS is in continental drift analysis. Students are shown how to 'digitize' the longitudes and latitudes of points on the coast-lines of South America and Africa. They are given the position and angle of rotation of the 'best-fit' pole of rotation between South America and Africa (Bullard, Everett, and Smith, 1965) and are asked to rotate the continents back together again, using ROTS. When they carry out the required rotations, they find that in general their coastlines fit fairly well, but not exactly. In their explanation of the discrepancy between the expected and the obtained fit, they are asked to comment on the usefulness of coastlines for fitting continents back together again,

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and are made aware of the possibility of fitting different bathymetric contours other than the zero ('sea-level') contour. This exercise draws attention to the third or thickness dimension of continents and to processes such as sedimentation and vulcanism which modify the shapes of the continents.

It is convenient, and in fact quite appropriate, to relate this exercise in continental drift to one in paleomagnetism (Figure 1). Students are given a former (Triassic) pole for each of the continents, South America and Africa, and are asked to rotate those poles in the same way that the continents were rotated. Of course, if the two continents in Triassic time (about 200 million years ago) were then connected, they would have had the same paleomagnetic pole. The students are given actual poles, and are asked to comment on the source of the small discrepancy, about  $5^{\circ}$ , which persists after rotation. This exercise focuses attention on short-term polar wandering (secular variation) and the inaccuracies inherent in experimentally measuring paleomagnetism in rocks. It is believed that this approach, using ROTS to simplify the complicated calculations, leaves the students a maximum amount of time to think about some of the most important fundamentals of continental drift and paleomagnetism.

Incidentally, valuable to the student's experience for visualizing in three dimensions is plotting the data by hand

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before and after rotation, using an orthographic projection net. This produces a map of the Earth, on which only the continents Africa and South America appear. This also provides an opportunity for measuring the great circle distance between the paleomagnetic poles before and after rotation, by using the great circles of the orthographic projection. This serves to introduce the student to the concept of making angular measurements on spherical projection nets, paving the way for a more comprehensive training in later courses. Of course, the orthographic net is not the best net for making such measurements, but by choosing the central meridian judiciously (say, at 30W in the present example), these great-circle angles can be measured accurately enough.

### Conclusions

The use of a time-sharing computer system, such as APL, allows students of introductory earth science to explore some exciting fields more thoroughly than is otherwise possible. At the same time, the instructor has more flexibility in the design of the course. As a result, the student obtains a deeper insight into the variables related to the Earth and its history, and the introductory earth science course is made more interesting for both student and instructor.

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HOW MANY FOSSILS HAVE BEEN MEASURED?  
[ ]: 10

HOW MANY PARAMETERS DO YOU WISH TO ENTER FOR EACH FOSSIL?

[ ]: 6  
P1, P2, P3, ....ETC. REFER TO LENGTHS, WIDTHS, NUMBER OF COILS, ETC .

ENTER VALUES FOR P1

[ ]: 31 29 32 30 34 31 28 30 31 27

ENTER VALUES FOR P2

[ ]: 34.7 38.4 35.2 37.1 38.8 37.6 34.3 38.7 37.6 36.1

ENTER VALUES FOR P3

[ ]: 19.8 17.7 16.3 17.2 17.9 16.8 16.1 17.9 17.4 16.5

ENTER VALUES FOR P4

[ ]: 5.2 6.0 4.9 6.2 6.3 5.2 4.9 6.2 6.0 5.8

ENTER VALUES FOR P5

[ ]: 6.5 7.0 6.0 6.3 7.2 6.5 6.1 7.1 6.4 6.4

ENTER VALUES FOR P6

[ ]: 5 4 5 6 5 4 3 6 5 4

	MEAN	STD. DEV.
P1	30.500	2.953
P2	37.050	1.499
P3	17.060	0.659
P4	5.660	0.570
P5	6.550	0.414
P6	4.700	0.949

DO YOU WANT TO CALCULATE ANY RATIOS? YES TYPE Y, OR NO TYPE N.

Y  
TYPE THE PARAMETER NUMBER YOU WANT IN THE NUMERATOR(TOP).

[ ]: 2  
TYPE THE PARAMETER NUMBER YOU WANT IN THE DENOMINATOR(BOTTOM).

[ ]: 3  
THE RATIOS FOR P2 ÷ P3 ARE:

FOSS1	2.18452
FOSS2	2.16949
FOSS3	2.15951
FOSS4	2.15698
FOSS5	2.16760
FOSS6	2.23810
FOSS7	2.13043
FOSS8	2.16201
FOSS9	2.16092
FOSS10	2.18788

DO YOU WANT TO DO ANOTHER RATIO? YES TYPE Y, OR NO TYPE N.

N

SEIS  
ENTER A VALUE FOR V1

U: 6

ENTER A VALUE FOR V2

U: 8

ENTER A VALUE FOR H

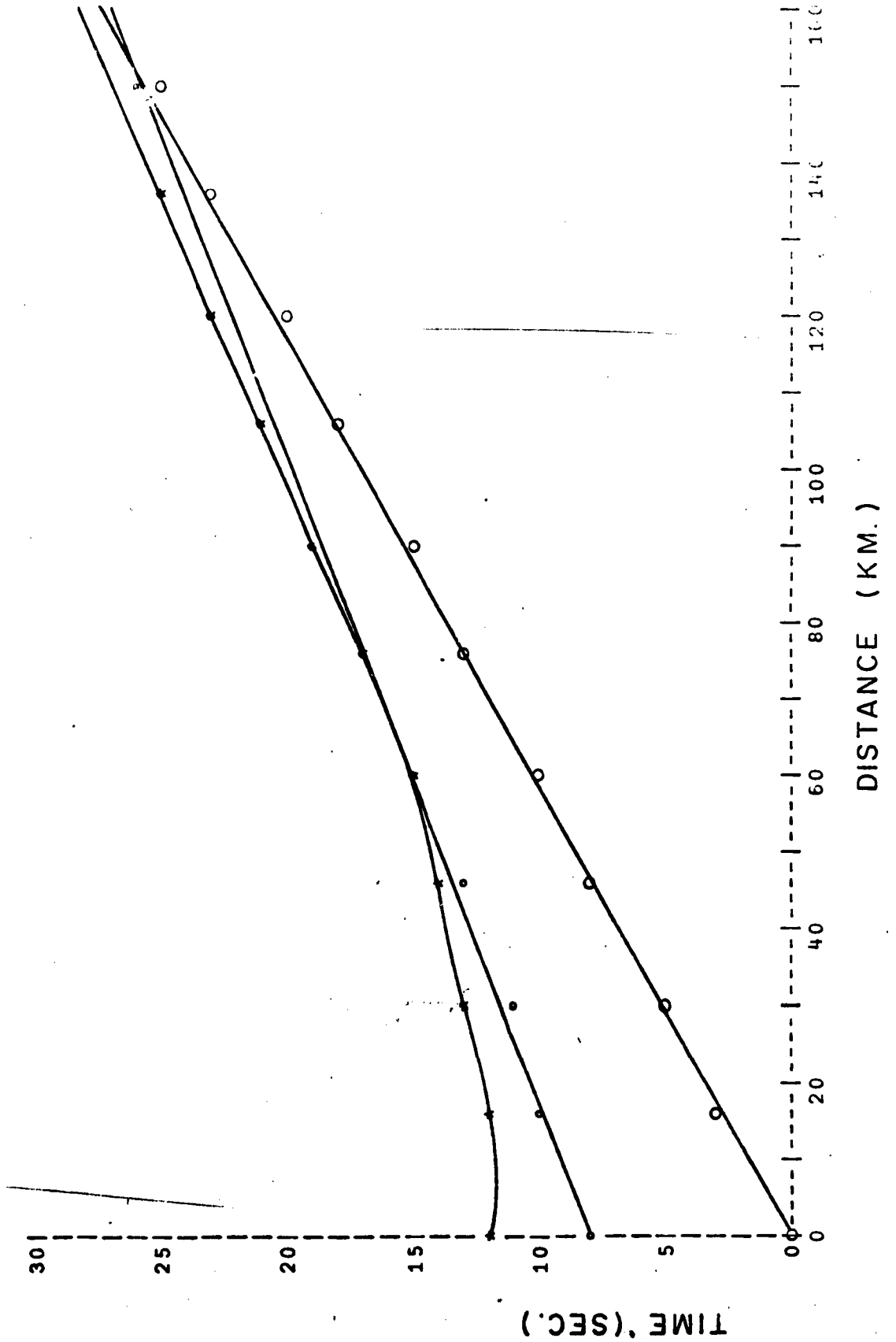
U: 35

ENTER A VALUE FOR DISTANCE IN KILOMETERS

U: 150

ENTER A VALUE FOR THE SIZE OF THE INCREMENT

U: 15



NOTS

ENTER LONGITUDES, DECLINATIONS

L: -49 0 30 140

ENTER LATITUDES, INCLINATIONS

L: 40 10 0 -50

ENTER ROTATION DATA: LAT, LON, ANGLE

L: -30 40 -50

INITIAL POSITION

ROTATED POSITION

INITIAL POSITION		ROTATED POSITION	
LAT	LON	LAT	LON
40	-45	73.6651157898	67.4010338665
10	0	24.8322501149	48.8991415907
0	30	-4.7599344565	59.9247383266
-50	140	-68.3381009725	-83.9074656381



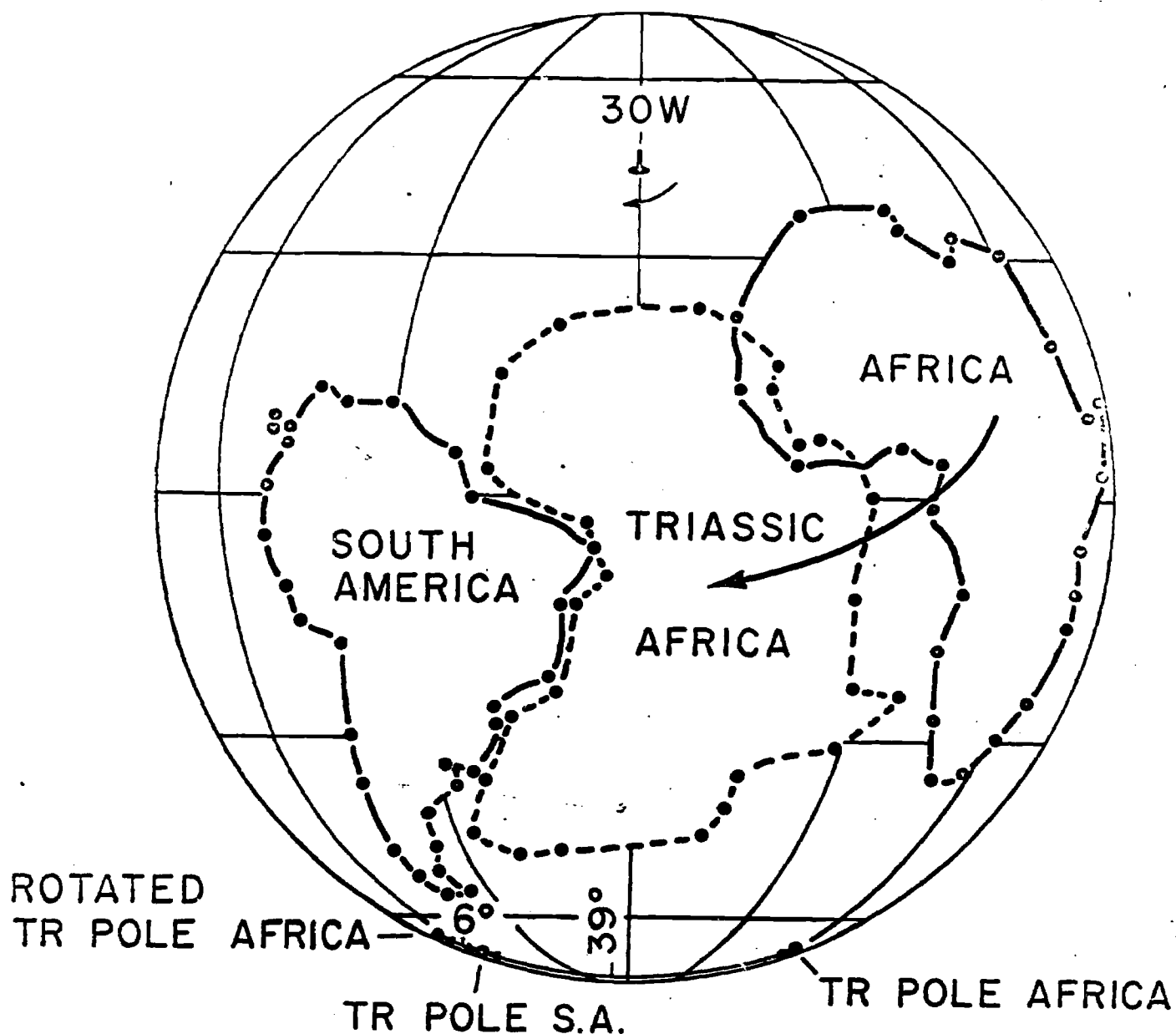


FIG. 1. DIGITIZED COASTLINE OF AFRICA ROTATED INTO BEST-FIT POSITION AGAINST SOUTH AMERICA, BY ROTATION  $-57.6^\circ$  ABOUT ROTATION POLE  $42.5^\circ\text{N}$ ,  $29.9^\circ\text{W}$ , USING APL PROGRAM ROTS. TRIASSIC PALEOMAGNETIC POLE OF AFRICA WHEN SIMILARLY ROTATED MOVES CLOSE TO TRIASSIC POLE OF SOUTH AMERICA.