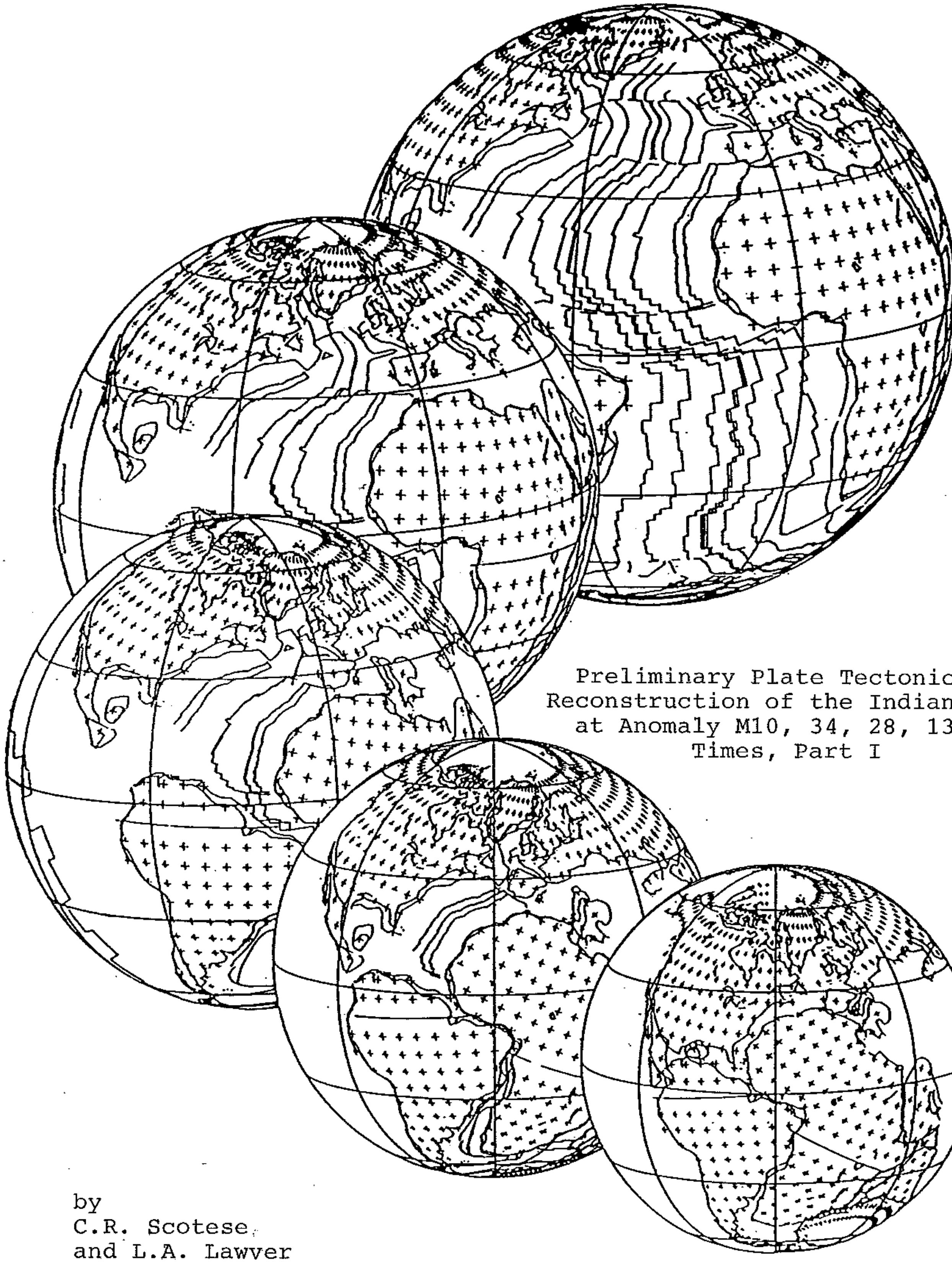
PALEOCEANOGRAPHIC MAPPING PROJECT
PROGRESS REPORT NO. 01-0684



Preliminary Plate Tectonic Reconstruction of the Indian Ocean at Anomaly M10, 34, 28, 13, and 5 Times, Part I

by
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Introduction

During the winter of 1984 work was begun on the Paleoceanographic Mapping Project at the Institute for Geophysics, University of Texas, Austin, Texas. The goal of the Paleoceanographic Mapping Project (POMP) is to produce a set of maps and film animations illustrating the tectonic evolution of the ocean basins during the last 200 million years. The basis of these global reconstructions is a new digital data base of linear magnetic anomaly data and sea floor bathymetry.

Initial support for the Paleoceanographic Mapping Project was received from British Petroleum, and as a result of their support a set of the Indian Ocean reconstructions were produced using a preliminary version of the POMP database. The six reconstructions described in this report represent the initial test of POMP data gathering procedures and mapping programs.

The maps in this report are based on the published rotation parameters of Norton and Sclater (1979), Sclater et al. (1981), Scotese and Ross (1982), Fisher and Sclater (1983) (see Appendix I)., and represent our current understanding of the plate tectonic evolution of the Indian Ocean. These maps highlight the remaining problem areas, and serve as the starting point from which a revised set of Indian Ocean reconstructions will be produced.

As discussed in the text, modifications and adjustments are required in the light of new linear magnetic anomaly and bathymetric data. A revision of these maps will be made (Fall 1984) using the Evans and Sutherland interactive graphics system at the University of Texas, Austin. The revised maps (1:10,000,000) will be published as Part II. of this report.

Contents

Figures 1 through 8 illustrate the plate tectonic evolution of the Indian Ocean, starting with the pre-breakup configuration of Gondwana and including maps for anomalies M10, 34, 28, 13 and 5. The magnetic anomalies used to reconstruct the ocean floor have been color-coded according to plate association (Africa, blue; India, red; Antarctica, green; Australia, yellow; and Madagascar, orange). Figure 9 is a digitized version of the tectonic lineations seen on the map of the geoid produced by William Haxby, Lamont-Doherty Geological Observatory. These lineations have been incorporated into the reconstructions.

In the remainder of this report, detailed critiques of each reconstruction are presented. The poles of rotation used to reconstruct the Indian Ocean for these six time slices are listed in Appendix I.

Discussion

Figures 1. and 2. Pre-breakup Reassembly of Gondwana

Two reassemblies of Gondwana are presented. The configuration of the continents shown in Figure 1 is based on the rotation parameters derived by Scotese and Ross (1982). In this reconstruction of Gondwana, which is a 'tighter' than most conventional reassemblies (Smith and Hallam, 1970; Norton and Sclater, 1979), there is a major region of overlap between the southeast coast of Mozambique, and a broad belt of Precambrian ultramafics that crop out along the northwestern coast of Dronning Maud Land.

This overlap may be permissable, however, because southeastern edge of Mozambique does not appear to be underlain by continental crust of normal thickness. A thick sequence of Meso-Cenozoic fluvial deposits derived primarily from the Limpopo and Zambezi Rivers, blankets the wide Zululand - Mozambique coastal plain (Dingle, 1976). No basement has been drilled; the oldest sediments encountered have been Neocomian conglomerates resting unconformably on Karoo (rift related) volcanics. The Lebombo line may mark the western edge of this thinned continental basement. A second Gondwana reassembly is proposed (Lawver et al., 1984) which, though similar in most respects, avoids this problem of overlap between Africa and Antarctica by moving Antarctica slightly northward with respect to Africa and rotating it, together with India and Madagascar, counter-clockwise (Figure 2).

In both reassemblies, there are several notable 'gaps' that were probably the original sites of small, continental fragments.

The gaps north and south of Madagascar were probably the original sites of the Seychelles and portions of the Madagascar Ridge, respectively. The space between Africa and Antarctica, south of Mozambique, provides room for the parts of the Mozambique Ridge and Aghulas Plateau which are thought to be of continental origin.

The fit between India and Antarctica, made primarily on the basis of crustal morphology, is confirmed by the match of Precambrian charnokite localities across the rift (Grew, 1982; Craddock, 1971). Especially note the fit between the Gunnerus Ridge and the island of Sri Lanka. The fit between India and Antarctica can be improved slightly by the closure of the small Mesozoic basin between India and Sri Lanka (Katz, 1978).

Though Madagascar originally was adjacent to eastern Somalia, its exact pre-breakup position is not well constrained. It is likely that the NW - SE trending coast of southwestern Madagascar was originally next to Tanzania and aligned with the northernmost coastal section of Mozambique. These two coastal sections probably slid past each other along the trend of the Davies Ridge during the earliest phases of rifting.

The reassembly of the eastern and western halves of Gondwana depends to a great extent on the fit of the eastern coast of Madagascar and and the western coast of India. These two linear coastlines were undoubtedly the site of considerable strike-slip movement prior to continental rifting (anomaly 34). Though the timing of this strike-slip motion is uncertain it is most likely to have taken place been anomaly M10 and anomaly M0 times.

Figures 3. Reconstruction at M10 - M11 Time

The eastern and western halves of Gondwana rifted apart during the Middle - Late Jurassic as the Somali and Mozambique basins opened along a series of N-S trending fractures. By anomaly M10 - M11, the Soimali basin had opened slightly more than halfway. The positions of the continents shown in Figure 3 are based on the rotations derived by Scotese and Ross (1982).

An alternate dating of this rifting event has been proposed by Rabinowitz et al. (1982). In their model, the Somali Basin is completely open, and Madagascar is in its present position with respect to Africa, by Anomaly M10 time. This model is untenable because it results in some overlap between southern Madagascar and Antarctica and requires a decoupling of the Somali and Mozambique basins (Lawver et al., 1984).

It is interesting to note that when the M11 anomalies in the Somali Basin are refitted, a slight gap remains between the M10 anomalies on the African and Antarctic plates (overlap would have been expected). This gap may be the result of improper anomaly identifications, or more importantly may record the onset of relative motion between India and Madagascar. By moving Antarctica and India slightly northward with respect to Madagascar, it is possible to refit the M10 anomalies in the Mozambique Basin.

By Anomaly M10 time the South Atlantic had just begun to open. Anomalies M12 - M10 in the western part of the Natal Valley record this earliest phase of opening. It was also approximately at M10 or M11 time that sea floor spreading commenced between

India and Australia/Antarctica. Anomalies in the Perth Basin and southwest of the Exmouth plateau mark the opening of the south-central Indian Ocean.

The timing of the rifting between Antarctica and India has important plate tectonic implications for the western Indian Ocean Basin, and in particular for the timing of strike-slip motion between India and Madagascar. If there was significant sea floor spreading between India and Antarctica during the time interval between Anomaly 10 and Anomaly 0, and if the rate of sea floor spreading in the Mozambique Basin remained roughly equivalent to the rate of sea floor spreading in the Somali Basin during this same interval, then there must have been sinistral strike-slip motion between India and Madagascar on the order of 500 - 1000 km. between Anomaly M10 and Anomaly M0 times. Additional plate tectonic reconstructions for this time interval may help to better define the timing of this movement.

Figure 4. Reconstruction at Anomaly 34 Time

Just prior to Anomaly 34, at the end of the Cretaceous Quiet Zone, plate boundaries in the Indian Ocean underwent a major reorganization as India rifted away from Madagascar and began its rapid flight northward. A major magnetic bight was formed off the southwestern coast of Africa as the triple junction between Africa, Antarctica, and South America migrated westward, and Australia may have begun to slowly rift away from Antarctica, according to a revised dating of the sequence of anomalies in the Australia-Antarctic Basin (Cande and Mutter, 1982).

The relative position of Africa and Antarctica shown in Figure 4 (Norton and Sclater, 1979) is not well constrained. It is difficult to refit the anomalies that formed the S. Atlantic triple junction and at the same time overlap anomaly 34 on the Antarctic plate with contemporaneous African magnetic anomalies west of the Madagascar Ridge. A compromise fit has been proposed that, while reforming the S. Atlantic triple junction, slightly overlaps the magnetic anomalies in the Madagasacar Basin. It should also be noted (Figure 4) that this pole of rotation superimposes the southern part of the Madagascar Ridge with an aseismic volcanic? plateau located to the south of Crozet Island.

Though there is no record of Anomaly 34 on the Indian plate, Anomaly 33 has been identified and as shown in Figure 4, these anomalies place India adjacent to Madagascar with little or no offset. This interpretation is in conflict with the evidence for sinistral strike-slip movement prior to Anomaly 34 time. In order to resolve this apparent controversy additional reconstructions for the interval of time between Anomaly M10 and Anomaly 30 must be made.

Several lineations, derived from satellite measurements of the geoid (Haxby, 1984), have been plotted on Figure 4. These fractures do not follow the path of relative motion between Antarctica and India during this interval and, therefore, are probably not the trace of Early Cretaceous ridge-ridge transform faults. Rather, it is more likely that these features represent the propogation of younger fracture zones (post Anomaly 34) onto older oceanic crust. If this is the case, then these fractures are an unusual and, and as yet undescribed, plate tectonic feature.

Figure 5. Reconstruction at Anomaly 28 Time

At Anomaly 28 time the ridge in the center of the Mascarene Basin jumped to a position north of the Seychelles, adjacent to the western coast of India. This plate reorganization transferred the Seychelles from the Indian to the African plate, and the movement of the rift center adjacent to India resulted in the massive eruption of the Deccan Traps (Norton and Sclater,1979).

The reconstruction of the Indian Ocean at anomaly 28 time combines the pole of rotation from Scotese and Ross (1982) for India relative to Antarctica with the pole published by Norton and Sclater (1979) for the Africa/Antarctica plate pair. This composite reconstruction agrees well with paleomagnetic data from the Deccan Traps which place the southern tip of India at paleo-latitudes of 30 to 35 degrees S.

The relative positions of Australia and Antarctica are based on the interpretations of Cande and Mutter (1982). Note in Figures 5 and 12 that as a result of this early episode of rifting there is a slight overlap between the 90 E Transform (Australian plate) and the trace of the 90 E Ridge (Indian plate). It is also interesting to note that the trace of the lineaments observed on the map of the geoid (Haxby, 1984) precisely coincide with the orientation of the transforms and fracture zones that were active at this time.

Figure 6. Reconstruction at Anomalies 13 Time.

The rotation parameters of Fisher and Sclater (1983) were used to produce the reconstruction shown in Figure 6. Prior to Anomaly 13 time, India had collided with Eurasia (Anomaly 22) and Australia had begun to rapidly rift away from Antarctica (Anomaly 22 - 19). Relative motion across the 90 E Transform had stopped, and India and Australia now travelled on the same plate. In all its major features, by Anomaly 13 time the Indian Ocean had assumed a very modern character.

Figure 7. Reconstruction at Anomaly 5 Time

The rotation parameters of Sclater et al. (1981) were used to produce the reconstruction shown in Figure 7. The poles of rotation for this time are very well constrained and it is possible to match the trace of recent fracture zones, as well as contemporaneous magnetic anomalies.

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Appendix I. Poles of Rotation

	Latitude	Longitude	Angle
A. Gondwana reassembly			
1. Norton and Sclater (1979)			
Africa / Pole			
Madagascar / Africa	-16.3	-31.4	13.8
India / Africa	29.6	36.1	-56.8
Australia / Antarctica	11.9	30.8	-30.9
Antarctica / India	1.0	7.7	88.9
Antarctica / Africa	-2.4	-32.7	55.4
2. Scotese and Ross (1982)			
Africa / Pole	0.0	172.0	31.0
Madagascar / Africa	1.5	-92.6	22.9
India / Madagascr	20.0	26.1	-57.4
Australia / Antarctica	(see Norton and Sclater, 1979)		
Antarctica / India	-4.9	17.8	92.5
B. Anomaly M10			
1. Scotese and Ross (1982)			
Madagascar / Africa	1.5	-92.6	7.42
India / Africa	-21.7	-147.1	61.01
Antarctica / Africa	-13.3	-20.6	48.46
Australia / Antarctica	(see Norton and Sclater, 1979)		
C. Anomaly 34			
1. Fisher and Sclater (1983)			
India / Africa	21.8	25.5	-54.5
India / Antarctica	(see Norton and Sclater, 1979)		
Antarctica / Africa	12.0	-40.0	20.5
2. Norton and Sclater (1979)			
India / Antarctica	14.1	9.7	-66.2
India / Africa	18.7	25.8	-56.0
India / Africa (pre 34)	24.5	33.5	-59.0

Australia / Antarctica	11.9	30.8	-30.9
Antarctica / Africa	19.7	-43.8	19.2

3. Scotese and Ross (1982)

India / Antarctica	8.8	14.1	-69.6
India / Africa	12.9	-45.8	12.9
India / Africa (pre 34)	20.0	26.1	-57.4
Antarctica / Africa	1.3	-28.4	20.7
Antarctica / India	8.8	14.1	69.6

4. This study

Antarctica / Africa	.2	-37.5	20.9

D. Anomaly 28

1. Fisher and Sclater (1983)

India / Africa	20.7	27.1	-37.3
India / Antarctica	(see Norton and Sclater, 1979)		
Antarctica / Africa	7.5	-34.5	13.0

2. Norton and Sclater (1979)

India / Antarctica	17.4	10.9	-42.8
Australia / Antarctica	11.9	30.8	-30.9
Antarctica / Africa	20.1	-52.6	11.0

3. Scotese and Ross (1982)

India / Antarctica	14.7	9.9	-44.6
Australia / Antarctica	16.8	25.7	-27.5
Antarctica / Africa	(see Norton and Sclater, 1979)		

4. Lawver et al. (1984)

Antarctica / Africa	16.2	-49.4	11.8

E. Anomaly 13

1. Fisher and Sclater (1983)

India / Antarctica	11.9	34.4	-20.5
India / Africa	15.0	50.7	-18.5
Antarctica / Africa	3.3	-28.0	5.8

2. Stock and Molnar (1982)

India / Antarctica	11.68	31.81	-20.46
Antarctica / Africa	-2.7	-25.0	6.0

3. Scotese and Ross (1982)

India / Antarctica	10.2	36.9	-20.0
Antarctica / Africa	-2.87	-25.34	5.8

F. Anomaly 5

1. Sclater et al., (1981)

India / Antarctica	16.2	34.6	-5.9
Antarctica / Africa	7.8	-41.8	1.38

2. Stock and Molnar (1982)

India / Antarctica	8.7	35.56	-6.65

3. Scotese and Ross (1982)

India / Antarctica	2.9	43.0	-6.6
Antarctica / Africa	8.0	-42.0	1.6

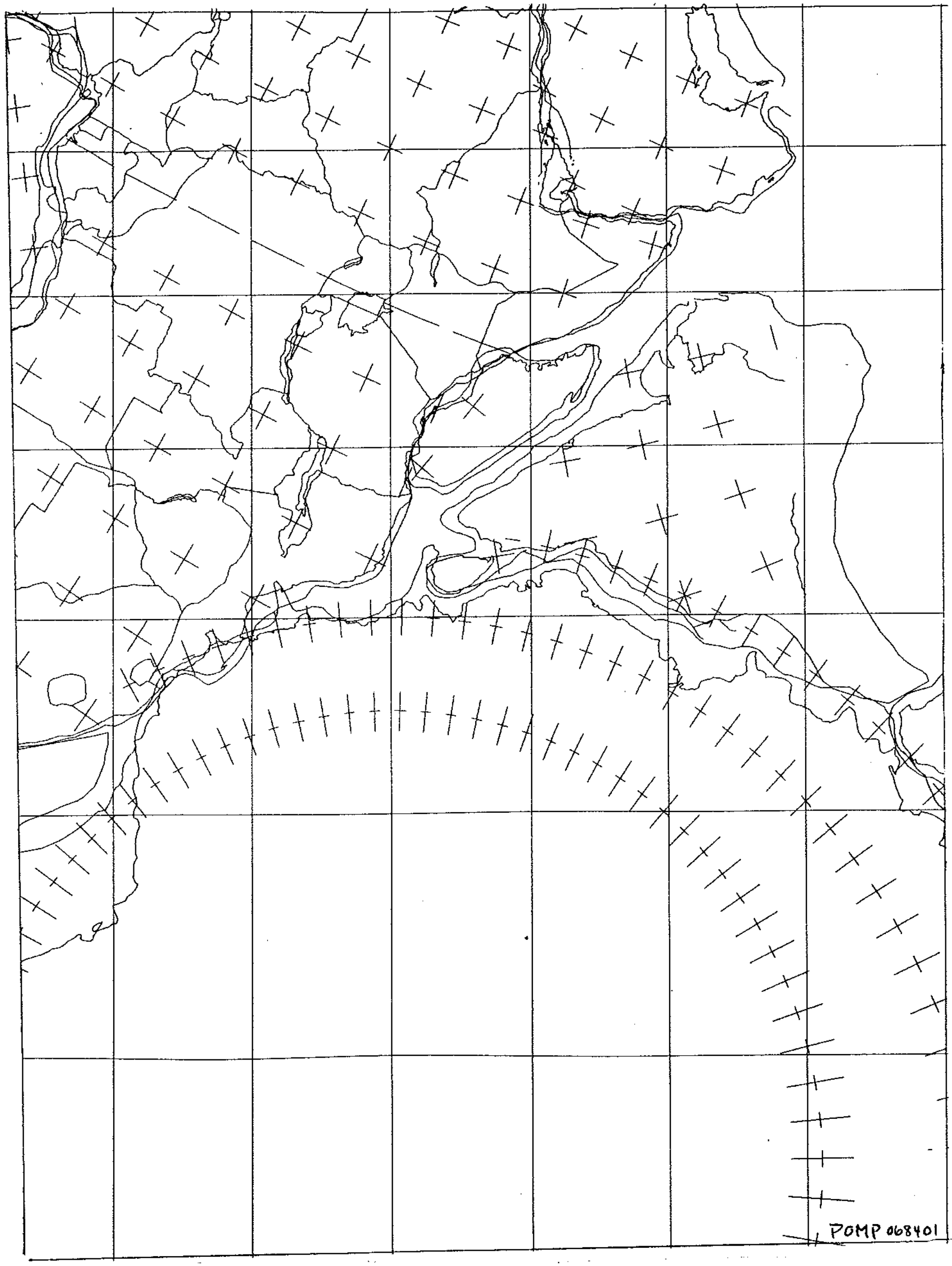

Figure 1. Gondwana Reassembly (Scotese and Ross, 1982)

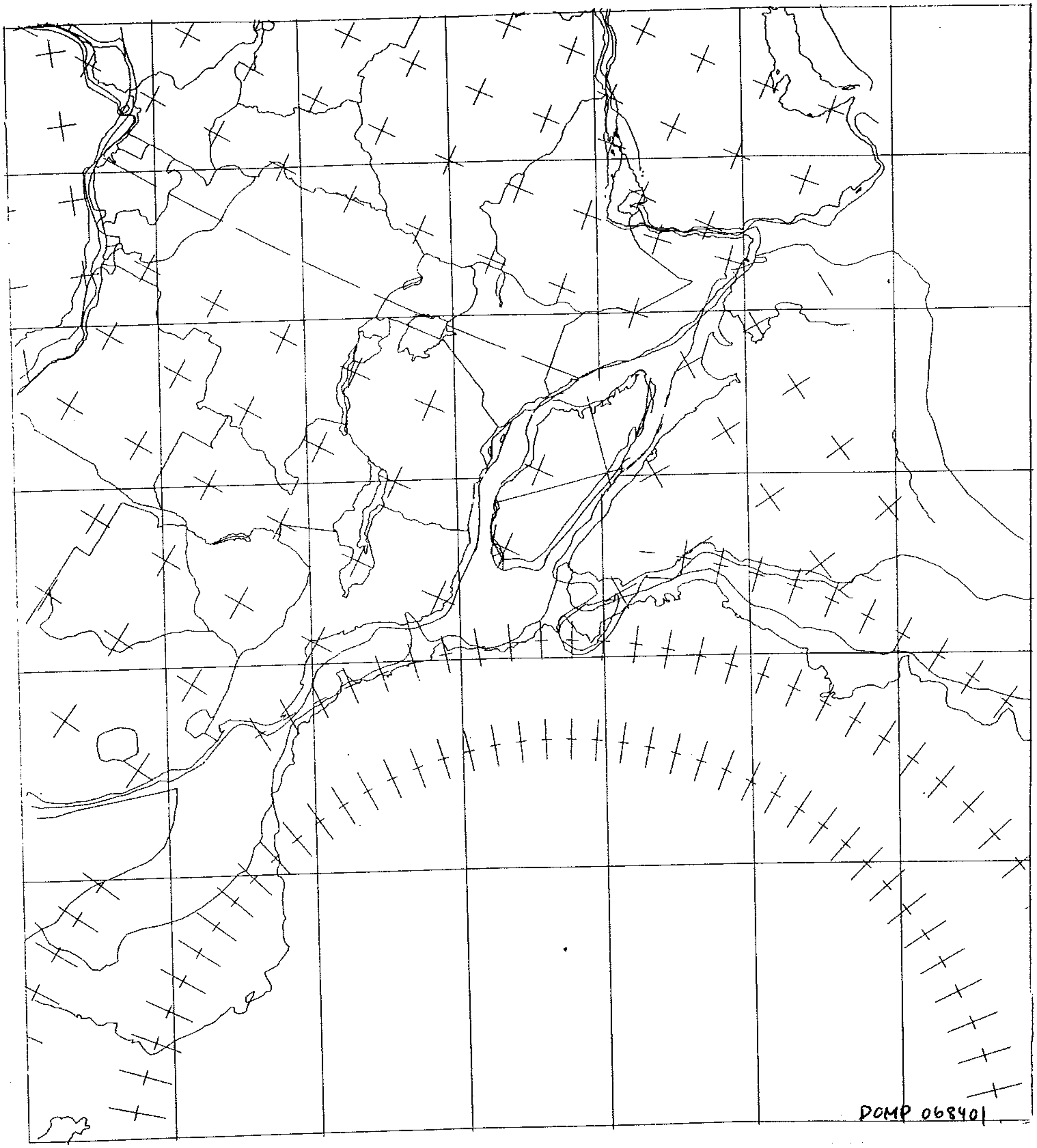

Figure 2. Gondwana Reassembly (Lawver et al., 1984)

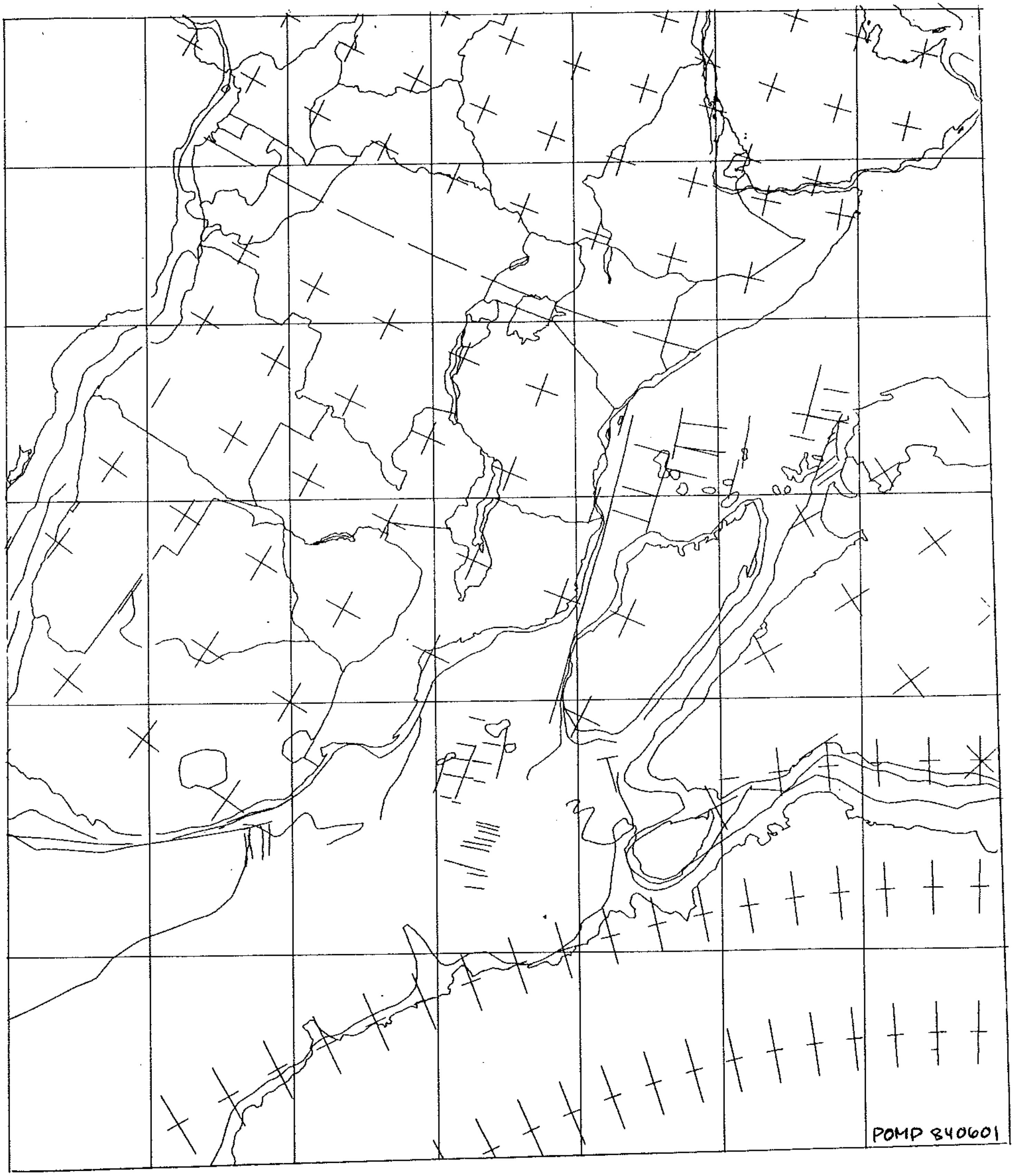

Figure 3. Reconstruction at Anomaly M10 - M11 Time.

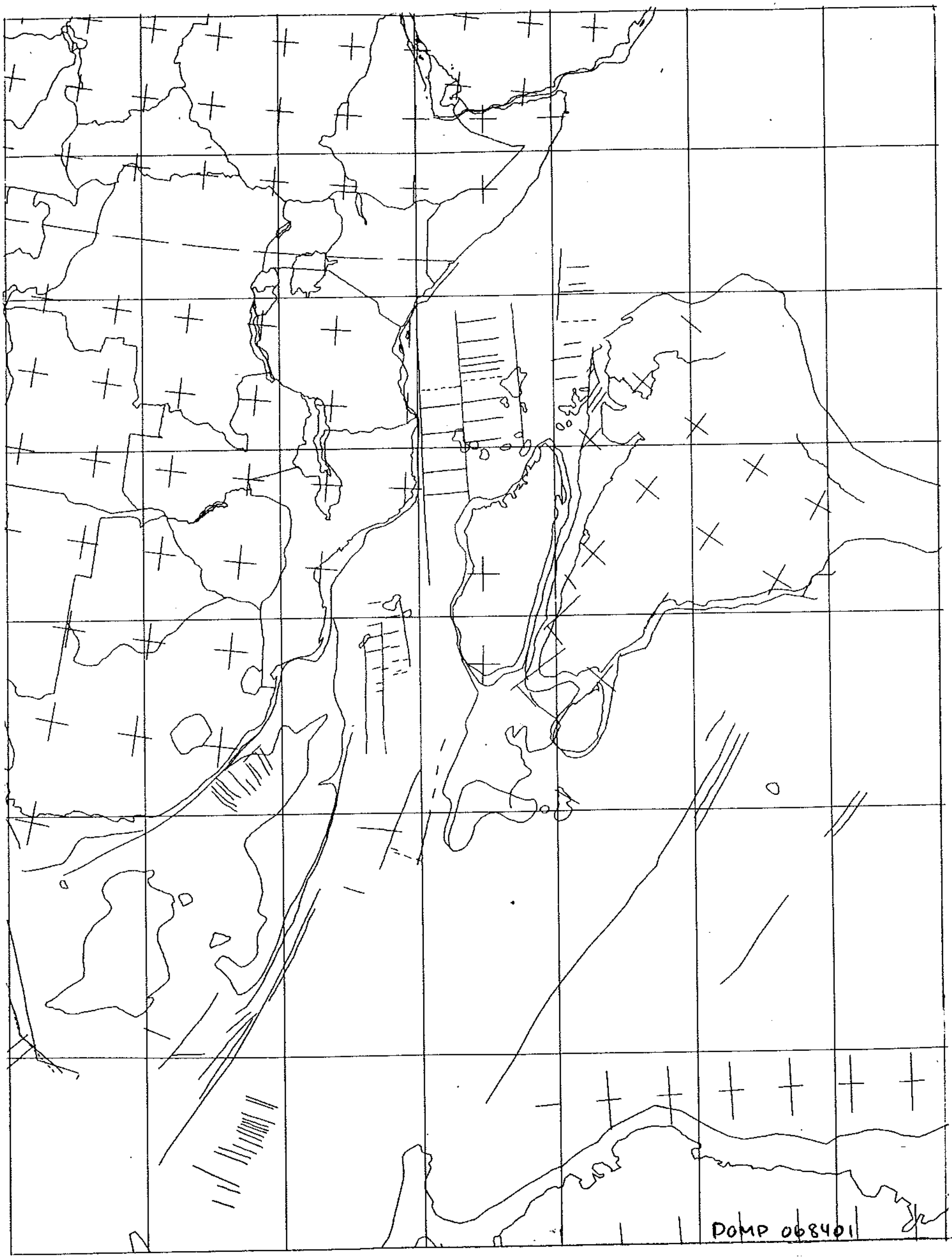

Figure 4. Reconstruction at Anomaly 34 Time.

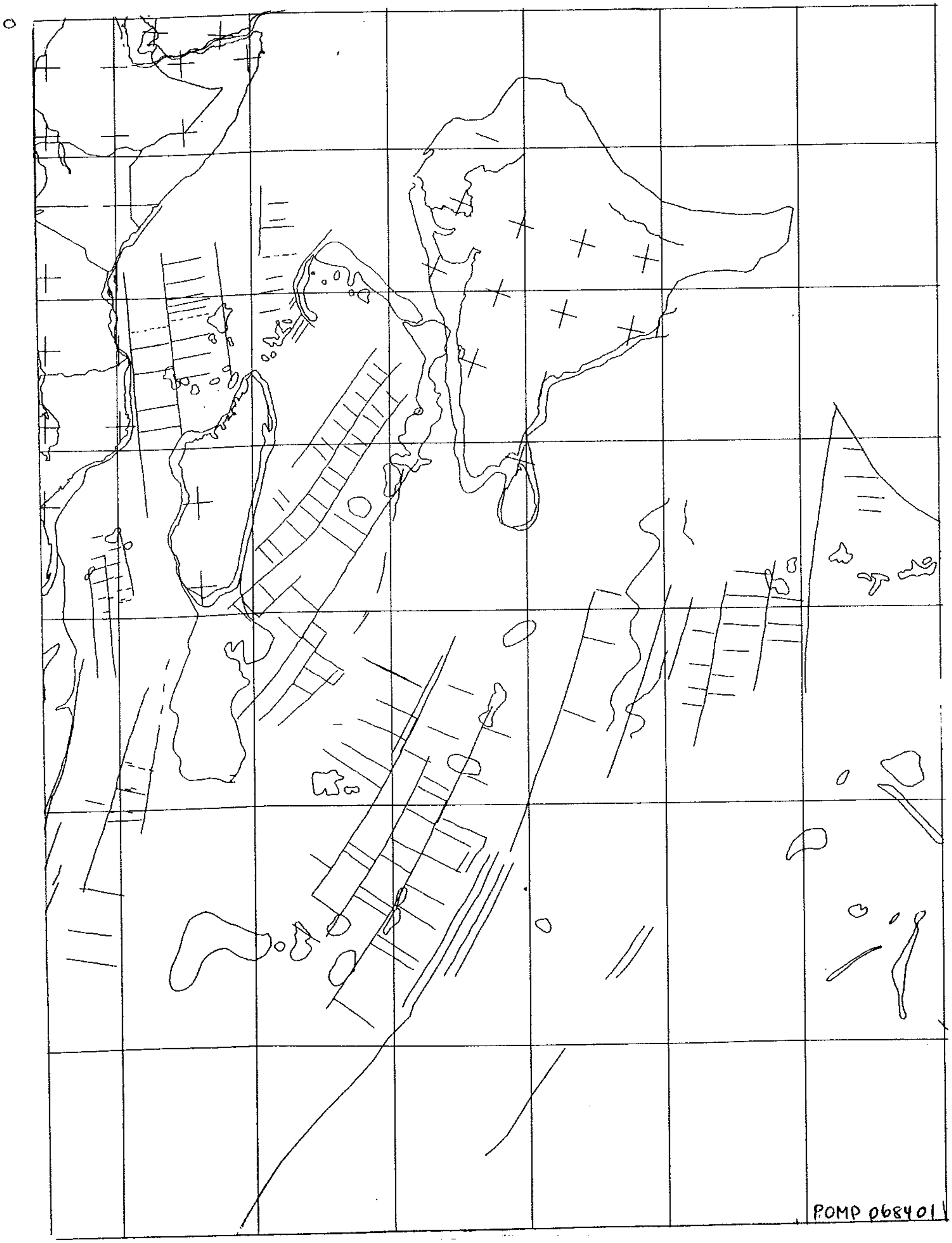

Figure 5. Reconstruction at Anomaly 28 Time.

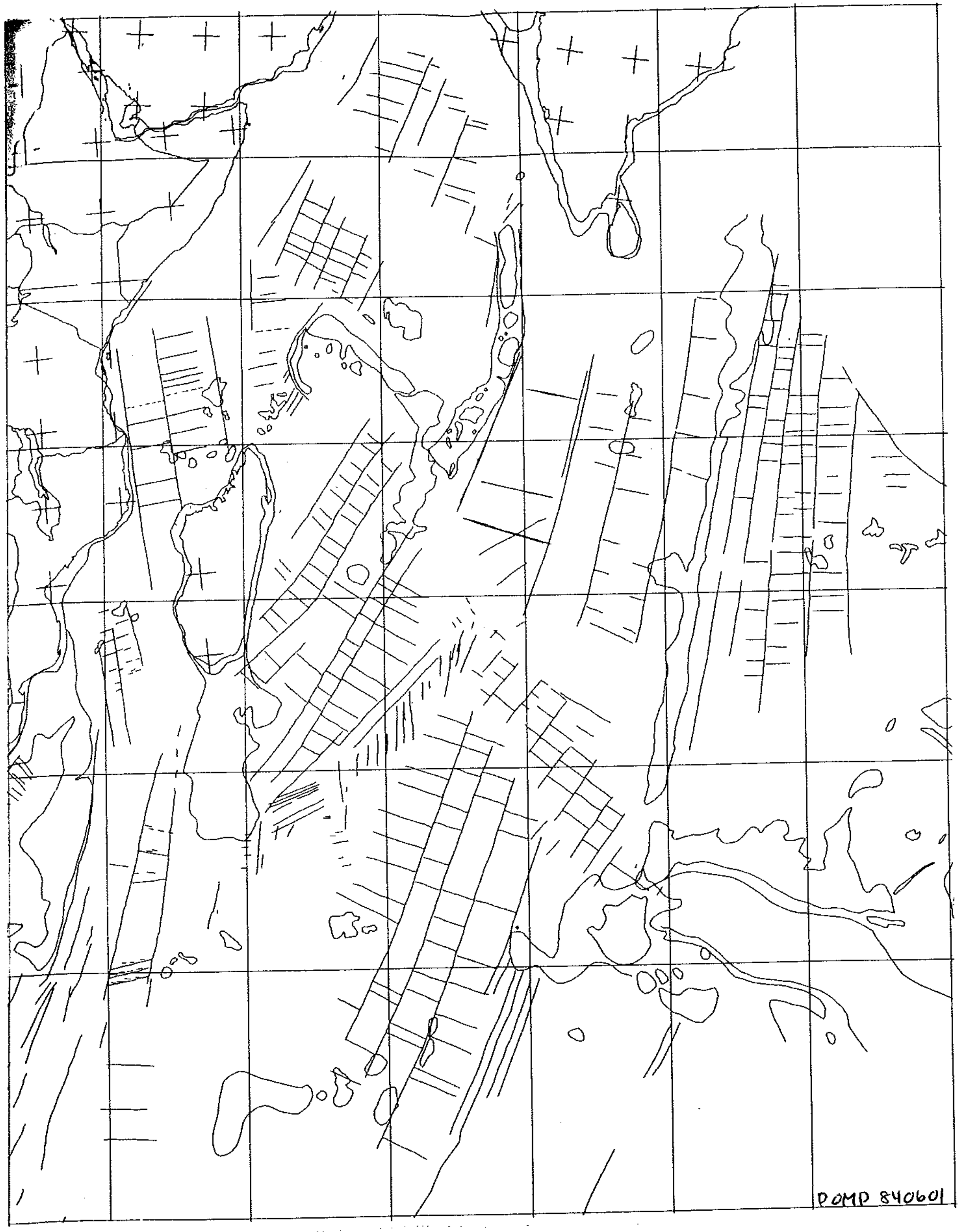

Figure 6. Reconstruction at Anomaly 13 Time.

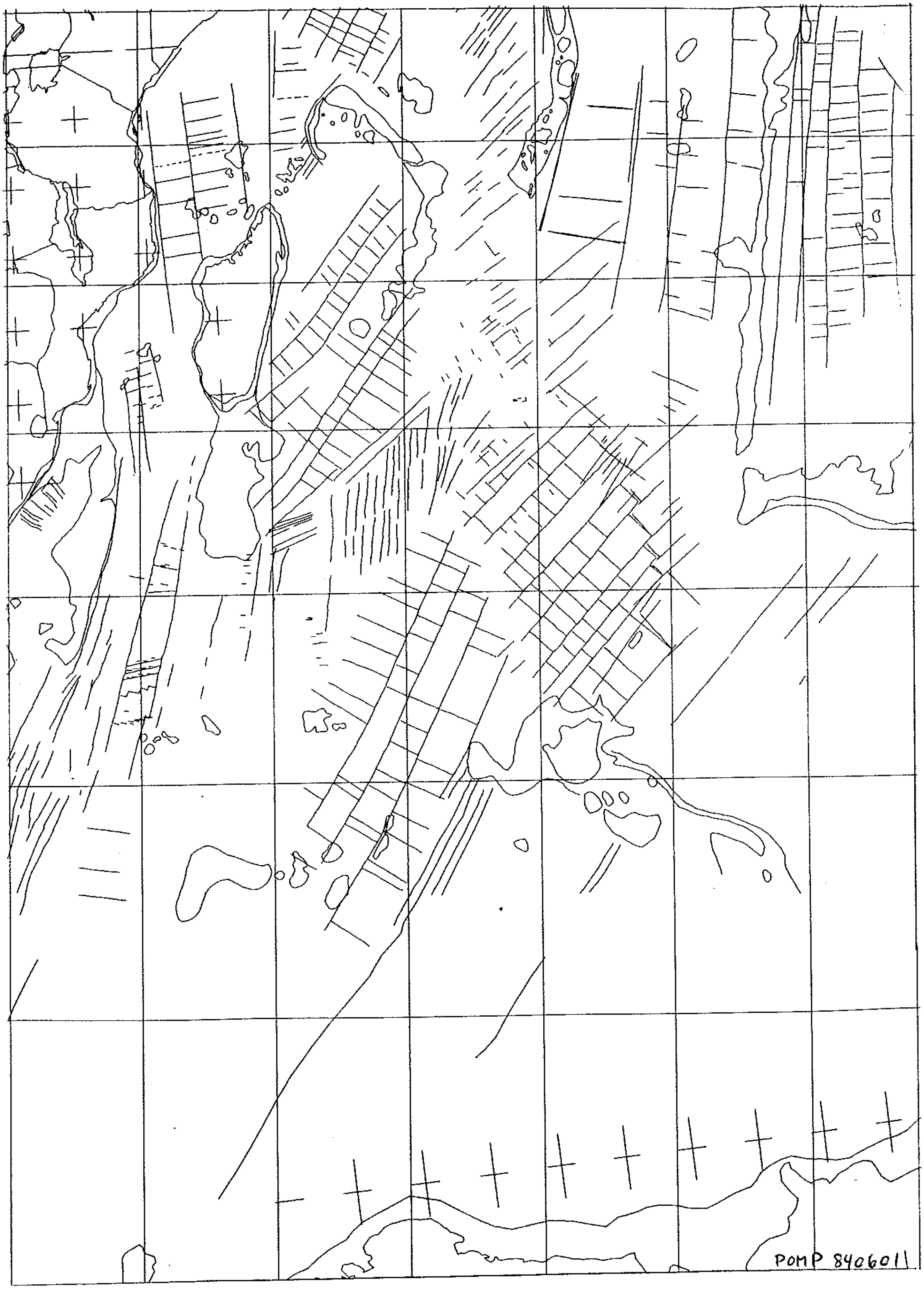

Figure 7. Reconstruction at Anomaly 5 Time.

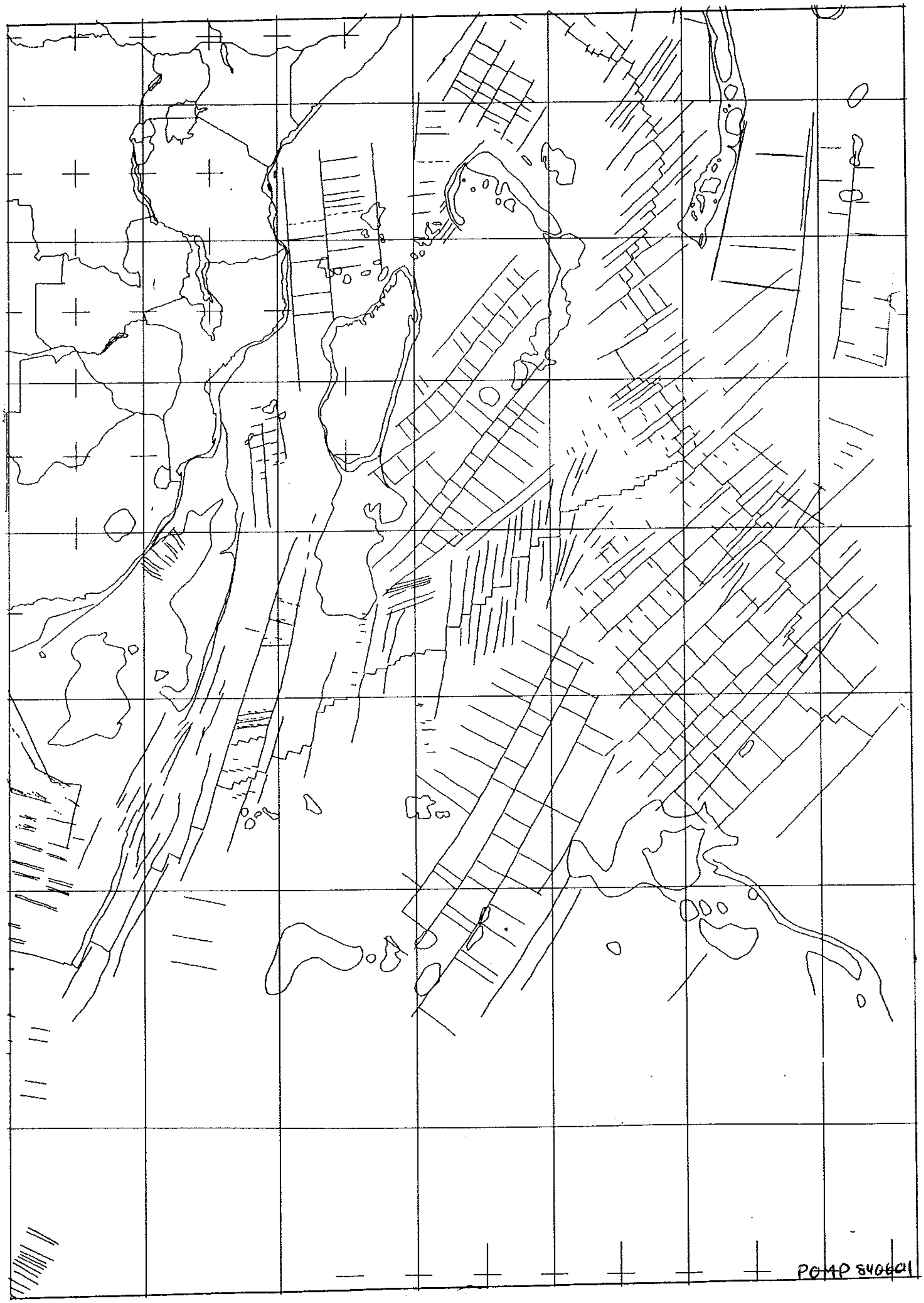

Figure 8. Linear Magnetic Anomaly and Tectonic Features Data Base.

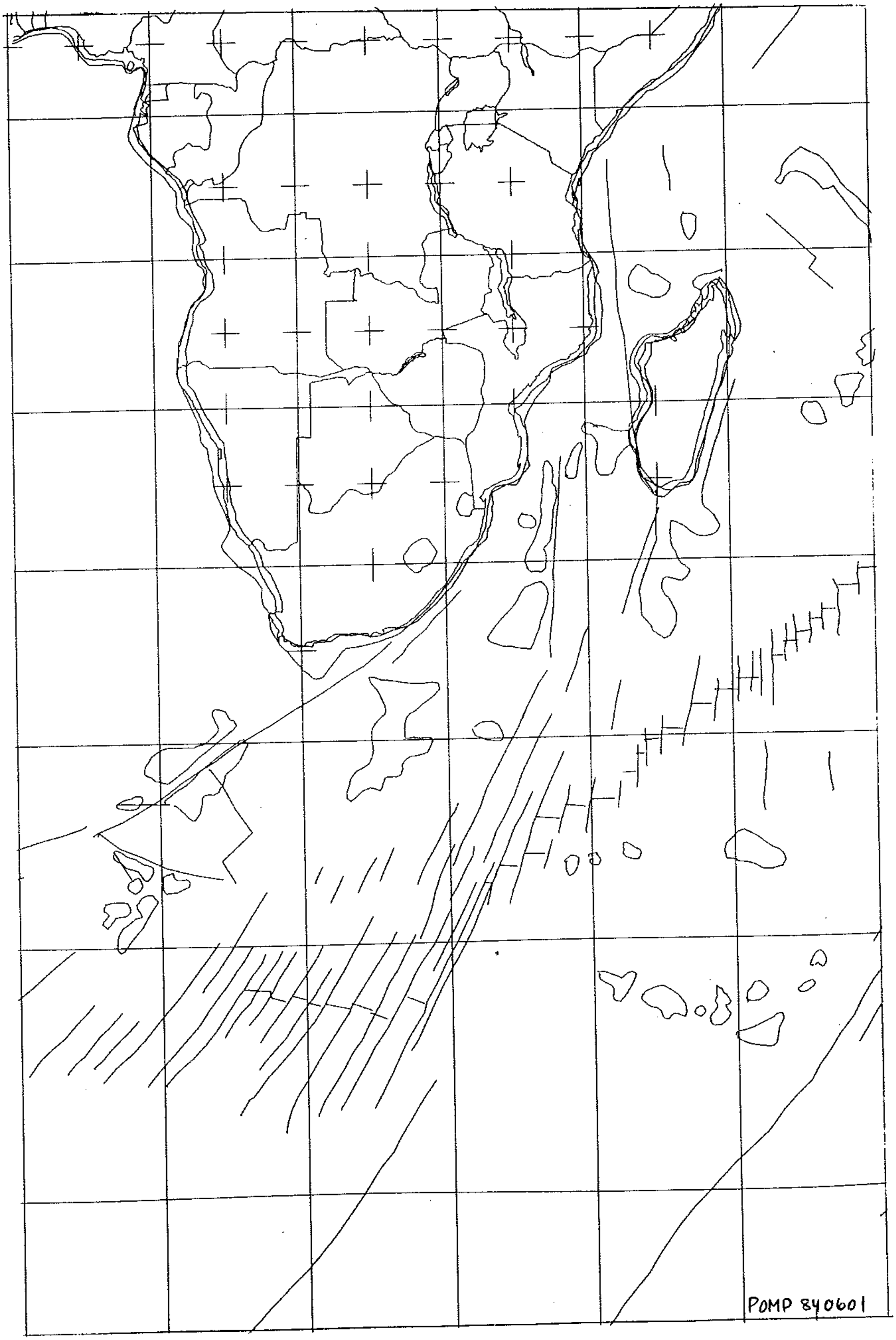

Figure 9. Tectonic Lineations from Haxby (1984).