SEISMIC REFLECTION INVESTIGATIONS OF SEDIMENTS ON THE ON THE EASTERN MURRAY ZONE

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures:

Tables:

Plates:

Abstract

A closely-spaced seismic reflection survey over the eastern Murray Fracture Zone between 127° and 133°38'W reveals a westward thinning wedge of terrigenous sediments due to eolian sedimentation from western North America. The wedge discontinuously thins to normal pelagic sediments in an apparently displaced manner from north to south across the Murray Escarpment. This displacement is due to the effects of topography. On the basis of sediment thickness trends, there appears to have been no transcurrent faulting since deposition commenced. Preliminary data further suggest that sea floor spreading has not occured within the past 50 to 100 million years on this portion of the East Pacific Rise.

I. The Eastern Portion of the Murray Fracture Zone between 127° and 133°38'W

A. Background

Between June 12 to June 26, 1967, the Hawaii Institute of Geophysics used the R/V SITKIN, a chartered 156 foot converted LCI, to survey 2400 n.m. of track lines over the eastern Murray Fracture Zone. The survey was carried out between 127° to 133°38'W and consisted of twenty-three north-south traverses of 90 n.m. length, spaced at 15 n.m. intervals (see track lines, plate 1). The configuration of the track lines was such that the zone of maximum topographic relief was crossed by the north-south profiles, and the spacing allowed optimum resolution of magnetic anomalies.

The purpose of this survey was to learn more about the tectonic development of the Murray Fracture Zone. To accomplish this goal, the following operations were performed: seismic reflection profiling (to be discussed in the next section); magnetic profiling, using a Varian Model V-4937 proton precession magnetometer; and precision echo sounding, using a towed V-fin and a Ocean Sonic GDR-T recorder. In addition to these continuous recordings, six gravity cores were obtained. With the exception of precision depth recording (the recorder malfunctioned throughout most of the cruise), operations were successful.

B. Geomorphology

The Murray Fracture Zone, as a distinct feature, originates off the coast of California, west of Point Conception. It has been traced westward as far as the Hawaiian Swell. In its simplest form in the present study area, it occurs as a single major escarpment which marks an increase in regional depth across the zone from south to north (for example, see profile no. 9, plate III). This increase in depth north of the Murray Escarpment is one of the characteristic features throughout the area and generally ranges from 300-500 meters. As Menard (1964) observed, the Murray Fracture Zone also separates physiographic provinces distinct in other ways than depth. This is readily observed in the bathymetry of plate I and figure 1. Whereas the province south of the Murray Escarpment is characterized by seamounts, some with relief exceeding 2000 meters, the northern province has relatively few seamounts and all are small and scattered through an area of comparatively low relief. Further differences across the zone exist also. One of the characteristic features in many of the profiles north of the Murray Escarpment is the presence of a broad arch beginning at the outer limits of the survey area and abutting the escarpment. Another feature often found in the north is a rather large graben whose southern face is normally the Murray Escarpment. These observations lead to a more general statement: topography immediately north of the escarpment could be attributed to deformational mechanisms which shaped the Murray Fracture Zone, whereas to the south, topography is dominated by volcanism associated with the Baja California Seamount Province. The topography to the north is superimposed on a deep sea floor of abyssal hills which occurs between the Murray Escarpment and the Mendocino Escarpment. To the south the Baja California Seamount Province, between the Murray and Clarion fracture zones, abuts the Murray Zone, thus complicating the deformation associated with the development of the fracture zone.

Throughout the length of the zone a linearity of features is observed. Primary among these is the northeast-southwest trend displayed between the small seamount at the northern end of profile 2 and Erben Guyot at profile 20 south. (The structural implications of this are discussed by Feeney, 1968). Two secondary alignments are found here also: 1) the tendency for bathymetric features to parallel the strike of the Murray Fracture Zone as previously noted (Menard, 1964); and 2) a minor trend a few degrees west of north-south, which is observed at the same angle in the three seamounts of profiles 6-7, the two seamounts of profiles 10-11, and the two hills of profiles 17-18.

II. Application of the sparker to studies of oceanic sediments

A. System and Penetration

The continuous seismic reflection profiling system employed on board R/V SITKIN during this cruise consisted of the following components:

1) An EG&G Sparkarray, utilizing three electrodes, associated with a 5,000-joule power source, including a Model 231 trigger unit, two Model 232 power supplies, and two Model 233 2,000-joule capacitor banks.

2) A 100-foot hydrophone array consisting of three sections of 2½ inch diameter poly-vinyl-chloride tubing, respectively 25, 50, and 25 feet long, each filled with castor oil. The center section contains thirty-two Electrotech EVP-9B hydrophones wired in series parallel, while the leading and trailing sections are oil-filled blanks placed to give the 'eel' added towing stability.

3) Two Geospace Electronic Company (G.S.E.) Model 111-C seismic amplifiers.

4) An Alpine Model 465 PESR wet paper recorder.

5) One Crown Model 800 4-channel tape recorder.

The system was employed in the following manner: when underway the sparkarray and hydrophone array were towed respectively 60 and 150 feet astern. Electrical energy from a 6 kva, 230V, 60 cps Onan generator supplied power for the capacitor banks, associated power supplies, and trigger unit. The SITKIN'S generator supplied 110V, 60 cps power to run the recorder.

On command from the Alpine PESR recorder, the stored electrical energy in the capacitor banks and trigger unit was discharged at a repetition rate of 5 sec. through a 4-conductor neoprene-covered cable to the sparkarray. Within the array are three electrodes mounted as separate arrays of one (1) each. As the electrical energy is discharged through the electrodes, high intensity acoustic pulses are generated. A portion of this energy is transmitted down through the water column and is then reflected from the sea floor and sub-surface horizons. The reflected energy is received by the hydrophones and transmitted to the seismic amplifiers in the electronics laboratory. This signal was passed through the first GSE amplifier (which had filters set to accept a broad band of frequencies, from 20 to 205 cps), and then split into two channels. One channel was transmitted to the Crown tape recorder where a record of broad band frequency input was recorded; the other channel passed to the second GSE amplifier, where it was again filtered through a narrow band pass of 50 to 150 cps and channeled into the Alpine PESR wet-paper recorder. (For a more detailed analysis of the instrumentation and magnetic tape playback system used see Kroenke and Woollard, 1966).

In the portion of the eastern Murray Fracture Zone investigated during the present study, the maximum observed penetration was not more than 0.2 sec. and average values ranged from 0.1 to 0.05 seconds.

The maximum penetration which this system has achieved on University of Hawaii cruises has been well in excess of a second of reflection time (Kroenke, in Woollard _et al._ 1967). In view of the demonstrated capability of the system, it is concluded that the sparker records taken during this expedition to the Murray Fracture Zone reveal the entire thickness of sediments overlying the bedrock reflector.

B. Record Interpretation

Because the sonic impulse generated at the spark-array is three dimensional in nature, some care must be used in interpreting the data observed in the two dimensional print out of the Alpine recorder. This is especially true where the sea-floor is rough or deformed as in the present survey area. In general there are five types of spurious signals that may cause confusion in the interpretation of the data: 1) direct arrivals; 2) reflection multiples; 3) water surface reflection; 4) side echoes; and 5) point source reflections (EG&G, 1962).

1) If the distance from the sound source (spark-array) to the hydrophones is less then twice the distance from the hydrophones to the bottom, the first signal to be

recorded after zero time will be the direct water arrival from the source. From the earlier discussion it was noted that the distance between the sparkarray and the first phone is only slightly less than 100 feet. At all times during this survey, water depths exceeded the 200-foot minimum required by this formula. The direct arrival in the records is therefore incorporated in the 'noise' of the outgoing pulse at the top of the records.

2) In areas where very strong bottom reflectors are encountered, the returning bottom signals will often be reflected down from the water-air interfare and be again received after two or more round trips (surface to bottom). They appear in a position below the actual bottom at even multiples of the true depth from the sparkarray and hydrophones and may thus be distinguished from possible sub-bottom reflections.

3) Because in normal oceanic depths the sparkarray acts as a point source, radiating energy in all directions, part of the energy is reflected to the hydrophones off the water-air interface. As was the case with the direct arrival, this is of no concern in deep water and is again part of the outgoing pulse at the top of the records.

4) In areas having a rough or deformed bottom, side echoes from reflectors to either side of the traverse are often imposed on the records. These may confuse the interpretation of actual bottom and sub-bottom reflections.

Where an extremely rough bottom is encountered, the interpretation may become quite subjective.

5) Point source reflections are those received from distant point reflectors in the area where the traverse is being run. They are sharpest when the point source is in the line of the traverse and usually occur in the records as cross-cutting parabolas.

The general roughness of the bottom throughout the survey area occasionally made interpretation of the records quite subjective. The spurious signals of importance in this respect were reflection multiples, side echoes, and point source reflections.

In the interpretation of the reflection records the strip chart recordings were placed on a light table to insure maximum resolution. A transparent plastic sheet (Mylar) was then laid over the record and the bottom and sub-bottom reflectors were traced with a felt-tip pen. Ink tracings were made since the ink could be wiped off with a damp cloth later and the sheet used repeatedly. During this stage spurious reflections due to items (2), (4), and (5) above were removed. Finally, a master tracing of each 90 mile north-south traverse of the Murray Fracture Zone was made from the Mylar overlays on transparent paper. Plates II through VI are photographic reductions of these final tracings.

III. Sedimentation studies in the northeastern Pacific

Since Murray and Renard (1891) published their descriptions of 12,000 samples obtained by the "Challenger" and other nineteenth century expeditions, knowledge of deep sea sediments has greatly expanded. (Summarized recently by Arrenius, 1963; Bramlette, 1961; Griffin and Goldberg, 1963; and Goldbert in Shepard, 1963). As a result, general patterns of sediment types and origins are now available for most areas. Although published data from cores is still lacking in the area of this study, a number of valid conclusions may be inferred from studies in surrounding areas, particularly near the Mendocino Fracture Zone, which strikes nearly parallel to the Murray Fracture Zone some 900 km, to the north. These two great fractures form the boundaries of an extensive deep sea plain in which some applicable sedimentary studies have been carried out.

During the course of the present study, twenty-three north-south traverses of the Murray Zone were made from 127° to 133°38'N. longitude (plate I). In the course of this investigation seven gravity cores stations were made. Six of these stations yielded cores ranging from $3\frac{1}{2}$ to 9 feet in length, consisting of a homogeneous silty sediment of medium brown color described as "red clay" (Revelle, 1944). During one of the coring attempts a hard surface was encountered from which chips of basalt were recovered in the nose cone. Important additional information is available in the form of sediment thicknesses as revealed in the reflection records, showing a gentle seaward thinning of the sediment with distance from the coast of California. This will be discussed in detail in the next section.

The sediments of the eastern Murray Fracture Zone appear to have a rather complex depositional history. The potential sources of sediment are numerous, as are the agents of transport. The availability of sediment thicknesses as revealed in the reflection records is of significant value in the interpretation.

A detailed analysis of nearby sediments was undertaken as a result of the Scripps "Mendocino" expedition in 1960. During the course of that investigation fourteen short cores were taken in the deep sea plain between the Mendocino and Murray escarpments. The analysis of selected cores from that expedition are discussed here as being of a composition similar to sediment found in our area of the Murray Zone. Cores nos. 4, 5, 29, 30, shown in fig. 1, are located east and north of the eastern Murray Zone with core no. 4 located 86 miles east and core no. 30 located 300 mi. north. The sediment in cores 4 and 5 is typical of sediment found in the zone affected by terrigenous deposition from the continent. The sediments in cores 29 and 30 are typical examples of pelagic sediments found to the west. Nayudu (1965) analysed these "Mendocino" cores with the following results:

1. Core nos. 29 and 30 display a radiolarian-rich clay horizon in their upper part that grades out with depth and increases in thickness to the west. The surface sediments are silty clays having plagioclase feldspar (andesine-labradorite) as the dominant mineral. Fresh and partly altered grains of pyroxenes, palagonites and basaltic glass, quartz, micronodules (manganese grains), zeolite, and zircon make up the remainder of the sediment, along with some glass shards of andesitic composition which increase in number to the west.

2. To the southeast, the radiolarian-rich clay horizon grades into sediment barren of radiolarians (core nos. 4 and 5). The eastern boundary shown in Nayudu's fig. 2 between radiolarian-rich and radiolarian-barren horizons lies at the seaward edge of the California Abyssal Plain. If we project this boundary south, then only the first few crossings of our cruise area would fall within the radiolarian-barren zone.

Cores 4 and 5 also have silt-size plagioclase (andesine-labradorite and oligoclase) as the dominant mineral. Other inorganic components of the sediment are quartz, fresh and partly altered pyroxenes, basaltic and occasionally green hornblende, basaltic glass, palagonite grains, and micronodules. Yellowish-brown aggregates (probably altered palagonite grains) predominate in the sand-size fraction of the sediment. Zeolites occur in the sediment and their concentration increases with depth. In addition, zircon, rutile, and geothite or hematite were observed in these sediments.

Generally all of Nayudu's cores may be described as red clay. In all cases the sand-size inorganic components were mainly composed of volcanic material of basaltic composition, and of manganese grains. The amount and grain size of the volcanically-derived constituents of all the cores increased with depth.

From the analysis of those cores, coupled with several dredge hauls on the Mendocino Ridge which recovered pyroxene-rich basalts, palagonite tuff breccias, and glassy basalts, Nayudu concluded that most of the red clays of the area have a direct genetic relationship to these volcanic rocks. He concludes that the major source of sediment is due to the decomposition of submarine volcanics derived locally.

Although Nayudu does not indicate in what manner these sediments were volcanically derived, it is obvious that there are only a few processes which could possibly be of significant importance: volcanic ash, subaerial or submarine erosion of volcanics, or by the formation of hyaloclastites (Rittmann, 1962).

The formation of ash in this area would necessitate volcanic sources at or near sea level. As McBirney (1963) has pointed out, the formation of ash could exceptionally take place at depths as great as 2,000 m., but the limit should generally be set at around 500 m. for basaltic magmas. The scarcity of seamounts in the Mendocino area (fig. 1) demonstrates how small the contribution from local submarine sources would be. Further, long distance eolian transport of ash could not account for the amounts indicated. The location of the present survey area on the edge of a seamount province with nearby guyots (Erben and Fieberling guyots) indicates that ash would be expected to be found in the sedimentary column but would certainly not account for more than a few percent of the total thickness.

Erosion of the Mendocino Ridge when it was at sea level (Menard, 1964) would have contributed some sediments nearby but would not be expected to have delivered erosional sediments to the positions of Nayudu's western cores. Nayudu ruled out deposition of terriginous volcanic material by turbidity currents.

Hyaloclastites are formed by the interaction of sea water with hot basaltic lavas during deep sea volcanism, causing fragmentation and hydration of part of the lava. This process apparently takes place at any depth on the ocean floor (Bonatti, 1966a and 1966b) and is not limited to shallow water. There is also ample evidence that hyaloclastic volcanism extensively affects the minerology and chemistry of bottom sediments in wide areas adjacent to the site of the outbreak. Turbulence and bottom currents created by the presence of a local heat source, as well as local bottom currents, scatter the finer debris to adjacent areas (Bonatti, 1966a). The problem of mineral assemblages is now confronted. The main component of hyaloclastic grains is palagonite, associated with normal basaltic glass and occasionally also crystalline basalt fragments including labradorite feldspar. (It should be noted that these crystalline phases represent only a very small part of the hyaloclastic production.) These feldspar crystals are formed before effusion, and it appears reasonable that pyroxene could form in the same manner. After the hyaloclastite grains settle, they react with sea water to form more stable phases such as minerals of the montmorillonite family and zeolites.

From the minerals found in the cores, it is obvious that the decomposition of submarine volcanics could only account for a small percentage of the present sediment. Of the components which Nayudu lists, only the palagonite grains, basaltic glass, zeolites, and the sand-sized basaltic grains may be accounted for in this way. The amount of feldspar or pyroxene contributed would be negligible. In support of this theory of volcanic derivation of the sediment, Nayudu believes that turbidity current transportation of material into the area would be at a minimum due to the north-south trending ridges of the Ridge and Trough Province which would inhibit seaward movement of sediment from the continent.

Menard (1964) on the other hand, believes the area of the fans (fig. 1) to be one in which turbidity current transportation from the continent through Delgada and Monterey submarine canyons has been of great importance. He further states that this sediment flow is controlled by the opposing escarpments of the two fractures, thus creating a broad, deep channel of sediment flow from the continent. Heezen and Laughton (1963) take a similar view, stating that the California Abyssal Plain (the combination of the Delgada and Monterey Deep Sea Fans extending 720 km from the coast) is not an area of sediment ponding but is a slope of equilibrium between deposition and erosion by passing turbidity currents. This would indicate that continental material is being deposited further seaward. Dill et al. (1954) have traced the leveed channel off Monterey Submarine Canyon out to at least 123°W to depths in excess of 4000 m. Menard (in Shepard, 1963) obtained a core from this channel containing gravel of terrigenous origin. This presents good evidence of the transporting power of turbidity currents in the channel. Dill also reported taking two cores, one from the channel, and another from the levee. Layers of quartz sand were observed, and the heavy mineral suite indicated derivation from metamorphic and volcanic rocks of continental origin.

Another source of sediment was indicated by Rex and Goldberg (1958) who investigated quartz concentrations of pelagic sediments in the eastern Pacific. They were able to determine the percentage of quartz in the carbonate-free fraction of pelagic sediments to within ± 3% by x-ray diffractometry. In the analysis of the many cores tested, a marked latitudinal dependency of the quartz concentrations was observed with a maximum at 30°N decreasing in both the north and south directions. The origin of the quartz particles in the pelagic sediments is thought to be eolian. The longitudinal dependency of the concentrations, when viewed in relation to the longitudinal patterns of geostrophic components of wind velocity and continental areas of arid land (fig. 5 in Rex and Goldberg, 1958), makes a strong case. The range of concentrations observed from cores in the regions north and south of the eastern Murray Zone is between 12 and 20%. Rex and Goldberg (1958) further state that with a quartz concentration of 20% it can be expected that at least 50% of the solid phases of the sediment are of eolian origin. A station on the Delgada Fan, however, shows a concentration of only 8 to 12% quartz, indicating a higher proportion of non-eolian sources near the continent.

Impressive evidence for tropospheric eolian transport of dust seaward from North America has been gathered by Bonatti and Arrhenius (1965). In 1961 at La Jolla, California, they observed and sampled a dust storm caused by strong easterly winds. When this sample was analysed, it was found to consist mainly of quartz, feldspar, mica, pyroxene, amphibole and volcanic glass, i.e., many of the major components of Nayudu's cores. This same storm was observed by U. S. Navy ships and aircraft off the coast of California near Santa Catalina Island where extensive dust clouds ranging from sea level to 900 m. elevation were being carried out to sea. Far from representing an isolated case, this general type of storm is a frequently observed phenomena of the area.

As for the andesitic glass shards which Nayudu observed, they are most likely derived from the westerly geostrophic winds and may represent a component of eolian material being delivered from eastern Asia.

This writer therefore attributes a rather complex sedimentary origin to the sediments of the eastern Murray Fracture Zone, with each of the previously discussed mechanisms of transport and formation contributing a certain amount of sediment.

Eolian transport has played a major role throughout the entire length of the zone, as evidenced by the close correlation between the components of Nayudu's cores and the analysis of dust carried by the easterly winds. The volcanic nature of the Murray Fracture Zone and the bordering Baja California Seamount Province should not be overlooked either. A contribution of locally derived volcanics throughout the entire length of the zone should be expected. This occurs both as ash and (primarily) hyaloclastites.

Another source of sediment could be thru turbidity currents originating on the Monterey Fan. This mechanism can be used to explain much of the observed sediment thickness data in the present area; however, lack of supporting evidence complicates its development in this thesis.

TABLE 1. Components of Sediments and Potential Sources
(from Nayudu's Cores)

Components	Sources		
	Turbidity Currents	Eolian	Local Volcanic
Cores 29 and 30			
Plagioclase feldspar	x	x	x-small
Pyroxenes	x	x	x-small
Palagonite & basaltic glass		x	x
Quartz	x	x	
Zeolites			x
Zircon	x	x	
Andesitic glass		x	
Cores 4 and 5			
Plagioclase feldspar	x	x	x-small
Quartz	x	x	
Pyroxenes	x	x	x-small
Hornblende	x	x	
Basaltic glass		x	x
Palagonite			x
Zircon	x	x	
Rutile geothite (hematite?)	x	x	

IV. Sediment thicknesses

A. Introduction and method of analysis

A compilation of average sediment thickness along the 23 N-S crossings of the eastern Murray Fracture Zone has been made. Approximately 30-40 measurements of one-way travel time were picked from the reflection records for each north-south traverse of the zone to yield an average value for sediment thickness. The values shown in table 2 represent maximum, minimum and average thicknesses across the zone, with the Murray Escarpment serving to divide the zone into northern and southern provinces. The values for average thickness were computed by measuring the sedimentary column at points over the tectonically undisturbed portions of the reflection records (plates II-VI). The zones north and south of the escarpment were treated separately, and an average value for thickness was determined throughout each province. When the observed trend of sediment thickness varied from the nearest hundredth of a second reflection time (table 2: points 12, 14-16N; and points 1, 4, 1, 14S), it was rounded off and plotted as an even hundreth of a second. Zero values at basement outcrops were not included in the averages since the effect of relief on the presence or absence of local ponding of sediment might thereby be seen in the data.

The average values of sediment thickness on the Murray Fracture Zone between 127° to 133°38'W have been plotted graphically in fig. 2 with thickness in seconds of reflection time plotted against distance west. Examination of the trends of the graph show two changes in regional deposition.

On the basis of a seismic velocity of 2 km per sec. for unconsolidated sediments (Ewing and Ewing, 1959) the maximum observed thickness of sediments in the area is 110 m. at profile 3 north and 100 m. at profile 6 south (table 2). Both thicknesses occur in slump-filled grabens. The average thickness of sediment on the northern flank of the Murray Fracture Zone west to 130°15' is 70 to 80 m. and on the southern flank west to 129°05' is 70 m. At these longitudes, the respective sediments thin discontinuously to 50 m. and continue westward at constant thickness. Reference to fig. 2 reveals several deviations from the general trends of sediment thicknesses. These anomalous sediment thicknesses may be either thicker (positive) or thinner (negative) than the average values. When viewed in relation to the bathymetry of plate I, the local structure of the individual crossings (plates II-VI), and the sources and types of sediment found in the area, these anomalous thicknesses may be used to reconstruct the depositional history of the eastern Murray Fracture Zone.

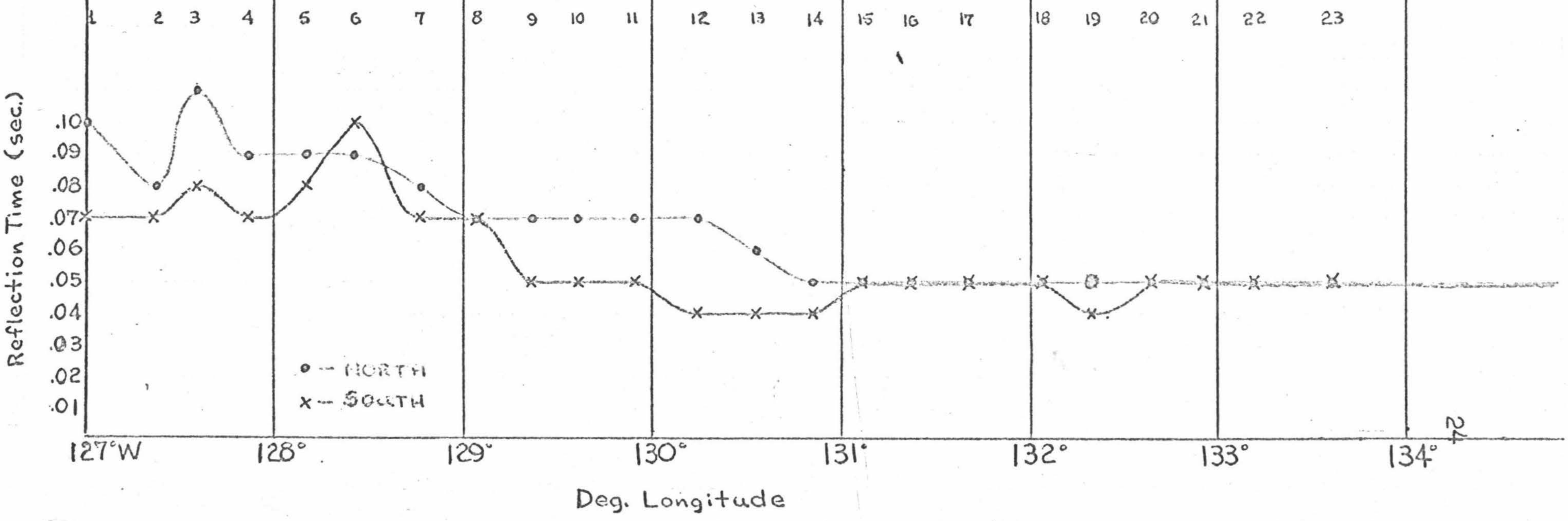
TABLE II

SEDIMENTARY THICKNESSES * MURRAY FRACTURE ZONE

PROFILE	NORTH			SOUTH		
	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
1	0.15	0.04-	0.10	0.09	0.04	0.07-
2	0.1	0.04	0.08	0.1	0.03	0.07-
3	0.20	0.05	0.11	0.13	0.03	0.08
4	0.15	0.04	0.09	0.14	0.04	0.07-
5	0.14	0.05	0.09	0.15	0.04	0.08
6	0.12	0.04	0.09	0.2	0.02	0.10
7	0.10	0.04	0.08	0.1	0.04	0.07
8	0.10	0.02	0.07	0.1	0.02	0.07
9	0.09	0.04	0.07	0.10	0.02	0.05
10	0.10	0.03	0.07	0.09	0.01	0.05
11	0.09	0.04	0.07	0.09	0.02	0.05
12	0.10	0.02	0.07-	0.08	0.03	0.04+
13	0.10	0.03	0.06	0.08	0.02	0.04
14	0.10	0.03	0.05+	0.05	0.01	0.04+
15	0.08	0.03	0.05+	0.07	0.02	0.05
16	0.09	0.03	0.05+	0.06	0.02	0.05
17	0.07	0.03	0.05	0.08	0.03	0.05
18	0.10	0.03	0.05	0.08	0.03	0.05
19	0.06	0.02	0.05	0.05	0.02	0.04
20	0.06	0.03	0.05	0.07	0.04	0.05
21	0.07	0.03	0.05	0.07	0.04	0.05
22	0.10	0.03	0.05	0.06	0.03	0.05
23	0.12	0.02	0.05	0.06	0.02	0.05

fig 2

Avg. Sediment Thickness
Murray Fracture Zone



B. Local effects

It is apparent from fig. 2 that local effects are influencing the sediment thicknesses. These are manifest in the peaks and troughs in the graph (especially to the south) which deviate from the smooth curve to be expected if local bathymetric features were not affecting the sedimentation pattern.

1. Northern Zone

In the zone north of the escarpment only two profiles show sediment thicknesses which deviate from the norm. These are profiles 2 and 3, which possess first thinner, then thicker than average sediments. Both abnormalities may be explained by their respective topography.

Profile 2, in comparison to the traverses east and west of it, is rather featureless. The flanking profiles are characterized by graben-like basins and topographic highs, particularly profile 3. It would be expected that the basins east and west of profile 2 would catch much of the sediment delivered to the area. In light of the greater depths of the basins flanking profile 2, slumping and solifluction plus whatever material is stirred up by benthonic organisms would gravitate down slope, thus adding to the average thickness of the flanking sediments.

The greater than average sediment thickness at profile 3 is interpreted as the result of ponding of sediment in numerous natural basins by: a) local turbidity current deposition; b) local rearrangement of sediment by benthonic organisms and drift; and c) transport of normal pelagic sediment down into the basins by solifluction and slumping from topographic highs.

2. Southern Zone

South of the escarpment, fig. 2 reveals sediments both thicker and thinner than the trend. These variations are to be expected in the environment of such a complex province with its many large and small seamounts, ridges, and basins. It was observed in compiling the data of fig. 2 that in the southern zone sediment thickness deviations from the main trend went from positive to negative as the trend was extended west. The southern zone has therefore been divided at 129°20'W into two sections:

a. Eastern section of the southern zone

The first eight profiles between 127° to 129°20'W fall within the eastern section. The 'normal' thickness of sediment in this section of the southern province is 0.07 sec. (fig. 2). Three profiles there (nos. 3, 5, 6) have anomalous values of average sediment thickness in this zone.

The greater average sediment thickness at profile 3 results from the trapping of sediment in numerous topographic basins. It is interpreted that sediment has gathered here due to: a) slumping and submarine solifluction; b) normal migration of sediment stirred up by benthic organisms; c) ponding of weak turbidity current sediment originating from both local sources and, perhaps, the Monterey Fan; and d) the trapping of whatever sediment is being moved by bottom currents. Although the bathymetry on the southern end of the traverse (plate II) is not available due to normal drift during a camera station, the writer believes the average value of sediment thickness given is nevertheless valid.

If the southern section of fig. 2 between profiles 4 and 7 is matched with the corresponding bathymetry of plate I, it may be observed that the thickening sedimentary column is in a local region of greater depth. Any turbidity current entering this regional basin would flow downslope toward the area crossed by profile 6 and thereby account for the thicker section of sediments observed there. Profile 5, with its average thickness 0.0I(±) sec. greater than the 'normal' averages in this part of the Murray Zone, has also acquired a share of the increased deposition.

The average value of sediment thickness at profile 6 is 0.03(±) sec. greater than the trend of thickness (fig. 2). As noted above, this profile is centered on the regional north-south basin. This trend towards greater depth is manifest here as two separate basins: 1) a deep, step-faulted graben, beginning just south of the escarpment, bounded on the south by a seamount; and 2) a low flat basin bounded by seamounts.

The graben contains a maximum thickness of 0.20 sec. of sediment. Much of the thickness here appears to be associated with slumping, as is evidnet from the tracing of profile 6 in plate II. This shows large slump-like features originating from the topographic highs north and south of the graben. To the east on profile 5 the sea floor is not only higher, but possesses a thinner cover of sediment. These observations would indicate additional mass movement of material from the east. Similar evidence bearing on the probability of mass movement from the west at profile 7 is not possible because the sparker was not operated while lowering a camera there. However, the regional bathymetry does not rule out the possibility of slumping from this direction.

The second basin of profile 6 contains approximately 0.1 sec. of sediment, but with no indication of the large scale slumping noticed previously. There is evidence however for some movement of material down the flanks of the adjoining seamounts in that the sediments lap against their respective flanks. It would appear then that the greater thickness here is due primarily to ponding of sediment.

b. Western section of the southern zone

In the remainder of the southern zone (west of 129°20'W) only two more profiles have average thicknesses significantly different from the general trend. Both of these deviations occur west of the wedge of sediment which at 129°20'W thins to a 'normal' thickness of sediments. The term 'normal' here refers to the 0.05 sec. average thickness of sediment that was observed to continue seaward past the end of this survey area at 133°38'W. It continues at least to 140°W, the end of a second cruise to the Murray Zone that followed completion of the one described in this thesis. The areas west of 129°20'W are both thinner than the general trend by 0.01 sec., and are associated with major seamounts with relief in excess of 2000 m. The eastern area is crossed by profiles 12, 13 and 14. Reference to table 2 shows the major thinning is at profile 13, where at least half of the southern traverse is on the rugged eastern flank of a seamount. The second thin area, at profile 19, is also on the rugged eastern flank of a large seamount (Erben Guyot). This phenomena may reflect the control of bottom currents operating in the area and will be more fully discussed in the following section.

c. Discussion of observed sediments on the eastern Murray Fracture Zone

The anomalous deviations from a smooth curve or trend of sediment thickness in fig. 2 described above, along with the more general trends revealed by the respective northern and southern curves, were used to reconstruct the depositional history of sediment along the Murray Fracture Zone.

First, an inspection of fig. 2 shows the anomalies fall into two groups: one between 127° and 129°20'W, generally having positive increments, the other, from 129°20' to the western boundary of the survey area, having negative values. The one exception to this grouping is at profile 2 north, where a negative deviation is found.

The eolian component of sediment delivered to the zone by tropospheric easterly winds, as noted, is of remarkably similar mineral assemblage to that found by Nayudu (1965) in cores from the northeastern Pacific between the Mendocino and Murray Fracture Zones. This author believes that analysis of the six cores taken during this survey will very likely show the same correspondence of composition.

Reference to diagrams of atmospheric circulation (such as those in Willett and Sanders, 1959) show the tropospheric easterly winds to encounter the dominant geostrophic westerlies off the west coast of North America. Such diagrams further indicate that this zone of diminution of wind velocity coincides with the general region of the present survey. Remembering that the wedge of sediment here is only a maximum 30 m. thicker than the 'normal' pelagic thickness further west, it is not difficult to attribute the observed trends of sediment thickness to the gradual decline in carrying power of the easterly winds. The fact that the 5½ foot core taken on profile 10 north, on the westward thinning wedge, is apparently a homogeneous pelagic red clay supports this theory.

The primary objection to an eolian origin to this wedge of sediments is the apparent displacement of its toe from north to south across the zone. This occurs at profiles 14 and 8 respectively. Reference to plates III and IV shows the relief of the southern area beginning to increase in the region of profile 8 finally culminating at the large seamount at profile 14. Due to the increased problem of side echoes when the bottom is very rugged, much of the sediment could be masked from view in the reflection records. This masking effect might thus explain the apparent displacement of the sediment thickness trends.

The other source of terrigenous sediments that might account for the westward thinning wedge of sediment is deposition by turbidity currents from the Monterey Fan. The arguments for this are based on the apparent topographic control exerted on sediment thickness trends. The separation of the toe of the wedge of sediment at profiles 8 south and 14 north is an example of how the bathymetry may be used to explain the trends of sediment thickness. Reference to the earlier discussion of sediment thickness variations serves to illustrate this.

The thicker sediments between profiles 4 and 7 south when matched with the corresponding bathymetry of plate I revealed a regional basin, aligned north-south. A hypothetical turbidity current from the east, upon reaching this basin, would begin to deposit sediment first in the area of profile 5 near the edge, but with most deposition occuring on the axis of the basin on profile 6. Further, it would be expected that the turbidity current would not continue beyond this trap to the west. The sediment thickness data shows this to be exactly the case.

North of the escarpment, the sea floor is much less rugged and here it slopes down to the west (plate I). A turbidity current from the east would therefore have the slope necessary for its flow. There also appear to be a number of basins aligned parallel to the strike of the Murray Escarpment, for example the basin outlined by the 5000 m. contour between profiles 8 and 14 just north of the escarpment on plate I. This is interpreted on plates III and IV as a graben lying at the foot of the escarpment. If a turbidity current were to enter the area from the east, the basins might act to channel the flow of turbidity currents.

Although there does appear to be some evidence for the operation of turbidity currents in the zone, there is also much evidence against it. Some of the major arguments against the idea of turbidity currents from Monterey Fan are: 1) the effectiveness of the north-south trending ridge at about 126°W in fig. 1 in inhibiting movement of sediments from the continental margin; 2) the lack of graded bedding, or of any visible layering, in the cores; and 3) the apparent absence of horizontal ponding of sediments in concordant topographic lows.

Although the north-south ridge in our area could check the flow of turbidity currents from Monterey Fan, it is not in itself grounds to rule out their existance. In the Gulf of Alaska for example (see the physiographic diagram in Menard, 1964) extensive abyssal plains are separated from the continental margin by similar north-south ridges. The strongest evidence against turbidity currents on the Murray Fracture Zone therefore are in the sediments.

From all appearances, the sediments in the zone are normal pelagic red clays. It is possible that the terriginous sedimentation which formed the wedge observed in fig. 2 occured during the Pleistocene when sea level was lower and surface run-off was significantly higher than now (Shepard, 1963). If this were the case, the turbidities lie beneath a layer of normal pelagic sediments deposited since the Pleistocene. The core taken at profile 10 north consisted of 5½ feet of apparently homogenous pelagic red clay. Based on a rate of accumulation for the pelagic sediments in the northeastern Pacific of 1 mm/1000 yrs. (Menard, 1964), this indicates an age of approximately 1.7 million years for deposition of the sediment cored here. Unless the station sampled an unusually thick section of pelagic sediments on a submarine slump, this argument against turbidity current deposition appears quite valid.

Until a detailed analysis of the sediment cores taken during this expedition is available, a conclusive answer to the problem of the origin of the westward thinning wedge of sediment must necessarily be speculative. Its existence, however, is rather good evidence of continentally derived terriginous deposition.

It should be noted that the column of sediments on the eastern Murray Fracture Zone are 'disturbed'. This relates to the observation that the profiles of plates II-VI are characterized by having sections of their sedimentary column removed, added, or otherwise affected by such submarine processes as slumping and associated local turbidity currents (Emiliani and Milliman, 1966).

In sum, this writer asserts that the bulk of evidence from this survey weighs heavily in favor of an eolian origin for the westward thinning wedge of sediment revealed by seismic reflection profiling on the eastern Murray Fracture Zone.

West of 129°20' all of the anomalies in fig. 2 are negative and occur entirely south of the escarpment. The latter observation is to be expected as the bathymetric map shows all the large scale features of relief to occur here. The general thinness of these sediments (0.05 sec.) is presented as evidence that terrigenous sources have not affected the deposition here. These sediments, then, are entirely the result of normal pelagic sedimentation. The abnormally thin sediments observed in profiles 13 and 19 might be expected in an area of normal pelagic sedimentation where possible sediment traps would be masked by side echoes resulting from the rugged topography there. Another explanation for these thinner than average thickness values could be that they result from bottom currents sweeping the area. The importance such currents as agents of sediment transport is well known (Heezen and Tharp, 1959). Observing profiles 13 and 19 in light of their respective bathymetric locations, a trend is noted. This refers to the fact that both profiles occur on the eastern flanks of seamounts with the higher crossings occuring west at profiles 14 and 20 respectively. If a bottom current is proposed in this area, moving in a southerly direction, the observed variations in sedimentary thicknesses are easily explained. Exactly such a current was measured to the east by Issacs <u>et al.</u> (1966) in the area of our profile 1. It was observed flowing in a south-easterly direction at an average velocity of 2.60 cm/sec. When such a current moving through the area encountered an obstruction, it would be diverted toward the flank until the regional north-south flow were encountered. When it resumed its north-south flow at a lower portion on the flank, it would add to the existing north-south component of flow and locally increase the current at this point and thus prevent sedimentation here. The east-west elongation of the seamounts in plate I shows the topography to support such a mechanism. This is especially true at the seamount crossed by profile 19 and 20 (Erben Guyot).

As for the area west of 129°20' in the northern province, we find no significant anomalies in the average thicknesses. The general trend is toward a gently decreasing cover of sediment out to about 130°50'W where the thickness becomes constant at 0.05 sec.

Among the more important discoveries resulting from this study is the relationship of the sediments to: 1) the right lateral transcurrent movement along the Murray Fracture Zone as proposed by Mason (1958) and Raff (1962); and, 2) the sea floor spreading hypothesis as proposed by Dietz (1961) and Hess (1962).

1. Transcurrent movement

Based on the correlation of north-south trending magnetic anomalies across the Murray Zone, an offset was observed. This offset ranged from 150 km right lateral in the eastern section of the zone (Mason, 1958), to the 640 km right lateral on the western section (Raff, 1962). It was proposed that this offset represented transcurrent movement along the fracture zone. If this relative movement has occured since deposition of the sediments in the present area, it should be expected that the data of table 2 will reflect it. Reference to fig. 2 reveals a vague conformity of the curves out to the area of profiles 7-8. West of this area, however, there is an 'apparent' displacement, amounting to 90 n.m. (167 km). A closer look at this figure shows the displacement to be left lateral: exactly opposite to what would be expected if the proposed transcurrent faulting had occured. Based on the information revealed by the present study, the writer concludes that no transcurrent faulting of the crustal blocks north and south of the Murray Escarpment has occured, at least since deposition of the westward thinning wedge of sediment shown by fig. 2. This conclusion is further supported by Feeney and Malahoff (in prep.) on the basis of their study of magnetic anomalies.

2. Sea floor spreading

Reference to the literature shows the average thickness of pelagic red clays in the northeastern Pacific to range between 200 to 500 m. (Raitt, 1956), (Hamilton, 1959). In the present area, however, average thicknesses of pelagic red clays were found to be a constant 0.05

sec., or 50 m. (assuming a velocity of 2 km/sec. for unconsolidated sediments). This thickness was observed to extend west from the base of the continentally derived wedge (described earlier) out to at least 140°W. Thus the western section of this area is found to possess an abnormally thin cover of sediment.

The thinness of these sediments cannot be explained by either topographic control or local differences in pelagic rates of deposition. In seeking an answer, the concept of a spreading ocean floor offers several plausible solutions: the basic premise of this hypothesis is that crustal material is extruded at the axis of a mid-oceanic ridge system. The crustal material to either side is then laterally displaced down the flanks of the ridge, carrying with it whatever sediments may happen to overlie it.

As Ewing and Ewing (1967) have demonstrated, if a constant rate of spreading is assumed, a graph, plotting sediment thickness versus distance from the crest of an oceanic rise, will show a steadily thickening section of sediment with increasing distance from the crest. When they plotted average sediment thicknesses from worldwide seismic reflection data over oceanic rises in this way, the graphs invariably displayed a similar pattern. Over a narrow band at the crest of the rise sediment was apparently lacking. Then, a gradually thickening layer of sediments was followed out from the crest for a distance of 100 to 400 km at which point a discontinuous thickening of the sediment occured. From this discontinuity, the sediment continued out at constant thickness. Although a temporal variation of sedimentation rates could explain the observed pattern as representing discontinuous sea floor spreading. They first propose an extensive cycle (or cycles) of spreading which terminated in the Late Mesozoic or Early Cenezoic. During this cycle it is suggested that all of the Paleozoic sediments were swept from the Pacific floor. Following this spreading, they propose a period of quiescence during which most of the observed sediment was deposited on a static crust. Finally, a new cycle of spreading is believed to have commenced about 10 million years ago.

Scholl and vonHuene (1968), on the other hand, have presented evidence from the Peru Chile Trench that sea floor spreading might not have occured in that area since at least Late Pliocene and possibly during most of the Cenezoic. This was based on the undisturbed nature of the trench sediments. If sea floor spreading were occuring at present, they argue, the sediments would be deformed here where the crust would be underthrusting the continent.

One way of testing the above hypotheses in the present area of the Murray Fracture Zone is to calculate the length of time necessary for the sediment to have accumulated. Using the rate of accumulation of pelagic sediments in the Pacific given by Menard (1964) of 1 mm./1000 yrs., and the lower rate of accumulation given by Arrhenius (1963) of 5 cm/100,000 yrs., the time required for deposition of the 50 m. accumulation of sediment on the eastern Murray Fracture Zone is calculated to be between 50 to 100 million years. These figures agree quite closely with those presented by Ewing and Ewing for the end of their first cycle of spreading in Late Mesozoic or Early Cenozoic, and also with the upper figure presented by Scholl and vonHuene.

Work by Pittman et al., 1968, supports the idea of recent spreading in the Pacific. However, if the East Pacific Rise is a part of western North America, as Menard (1960) has proposed, and if crustal deformation at any one time is mainly along the ridge axis by transform faulting (Sykes, 1967) then little or no recent displacement would be expected to have offset crustal blocks on either side of the Murray Fracture Zone discussed in this thesis. Therefore, even though the thickness pattern might be explained by the left lateral transform movement demanded by the sea floor spreading hypothesis there is no independent evidence that any such movement is taking place there.

It is possible that the trends of sediment thickness observed by Ewing and Ewing on other areas of the oceanic ridge system are simply masked in the present zone by continental sedimentation. If this is the case, the 50 m. thickness of sediment on the Murray Fracture Zone represents accumulation on a static crust before initiation of the present cycle, and the westward thinning wedge of sediment observed in the eastern section of the area represents continentally derived sediments that have been displaced to the west by the current cycle of sea floor spreading.

However, if we accept the evidence presented by Scholl and vonHuene against recent sea floor spreading and add to this the early cycle proposed by Ewing and Ewing, we can just as easily fit the present data to that proposed sequence of events. Perhaps the uniqueness of this portion of the East Pacific Rise, which may be overridden by the North American continent (Vine, 1966), reflects a more basic difference, and Scholl and vonHuene's arguments about deformed sediments are not applicable.

Although this writer favors the possibility offered by Ewing and Ewing, it will remain for further investigations to explore and answer these questions more completely.

V. Conclusions

As a result of this study, the following conclusions have been reached:

1) Sediment thicknesses have a direct relationship to submarine topography.
2) The westward-thinning wedge of sediments in the eastern part of this survey area is due to the diminution by the dominant geostrophic westerly winds of eolian transport from North America.
3) Sediment thickness trends indicate that transcurrent movement along the Murray Fracture Zone has not occured since the beginning of deposition.
4) Conclusions as to sea floor spreading are speculative because terrigenous sediments mask the zone in which conclusive evidence from sediment thicknesses would be bound.
5) The time required for deposition of the sediment is on the order of 50 to 100 million years.

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APPENDIX

Plate I:

This plate shows the ship's track during the present expedition to the Murray Fracture Zone. Each north-south traverse of the zone is numbered and corresponds to the reflection profiles of Plates II-VI. The bathymetry resulting from this survey was contoured by Dr. A. Malahoff with a contour interval of 200 m.

Plates II-VI:

These diagrams are the interpretations of each continuous north-south reflection profile. They are aligned along the Murray Escarpment. Each profile is approximately 90 n.m. in length. The vertical hachures are generally spaced at an hour, the tops being datum at 3750 m.

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