Cruise Report

A One-Ship Multichannel Seismic Survey of the Marquesas and Society Islands, French Polynesia

R/V *Maurice Ewing* Cruise EW 91-03

12 May - 10 June, 1991
Papeete, Tahiti to Papeete, Tahiti

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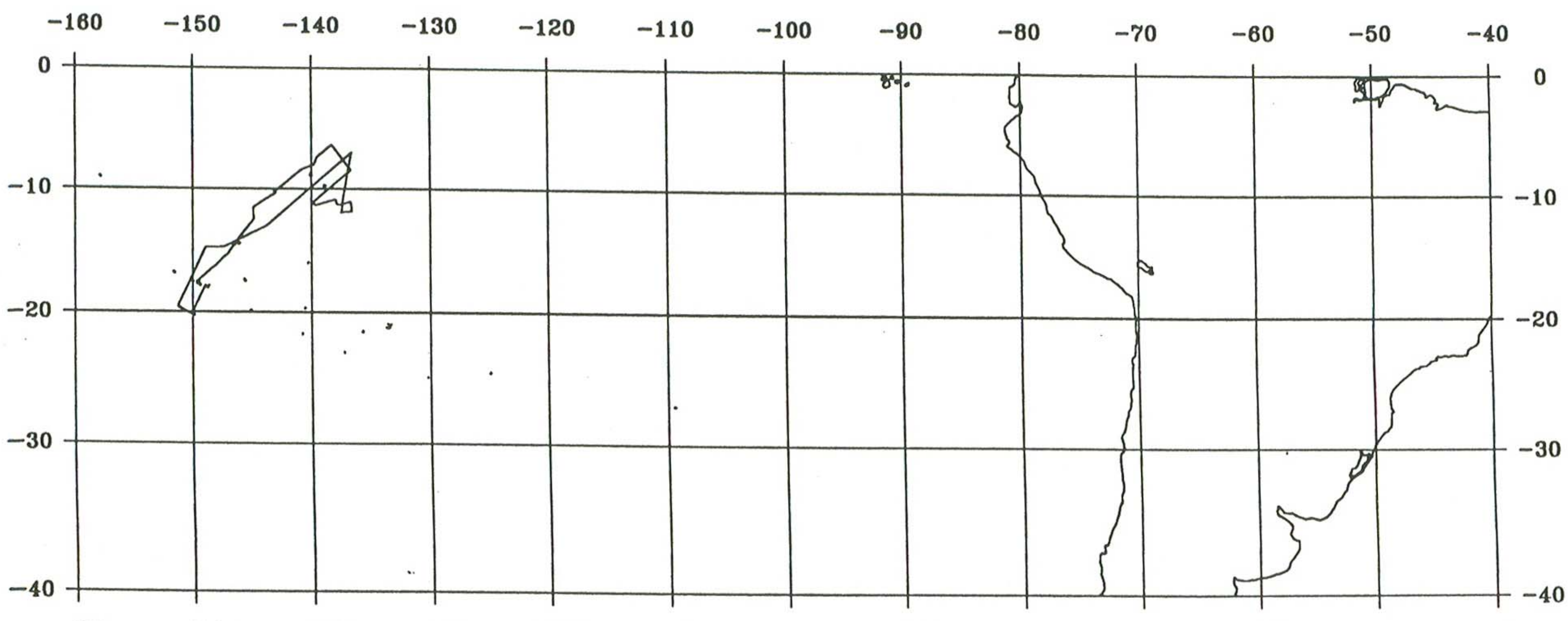
1.0 Background and Objectives

This report summarizes the operations carried out during the RN *Maurice Ewing* cruise EW 91-03, a multichannel seismic (MCS) reflection survey of the Marquesas, Society, and Tuamotu islands chains in French Polynesia. The principal goal of this expedition was to detennine from the deep seismic structure of these three hot-spot chains how the volcanoes were emplaced on the lithosphere and how the lithosphere responded mechanically to the loads. Along with existing MCS data from the Hawaiian chain, this information will provide new constraints on the penetration of the lithosphere by off-ridge volcanism and the lithosphere's subsequent thermo-mechanical evolution in several very different tectonic settings: young lithosphere (<20 Ma, Tuamotus), aging lithosphere (50 Ma, Marquesas), mature lithosphere (85 Ma, Hawaii), and thermally anomalous lithosphere (Superswell, Societies).

Planning for this expedition commenced in September, 1986 when the three co-Principal Investigators, Marcia McNutt, Bob Detrick, and John Mutter met with the French co-P.I., Jean Francheteau, at the Institut du Physique du Globe in Paris to detennine the scope of the program and sign a memorandum of understanding concerning the obligations of the various participants and the ultimate dispensation of the data. It was agreed at that time that this would be a two-ship expedition, with the U.S. vessel acting as both a shooting and receiving ship and the French ship towing a multichannel streamer. This arrangement of equipment would allow for collecting conventional CDP data by the American vessel and wide-angle reflections and ESP data by the French vessel.

Parallel proposals were submitted to both American and French funding agencies for support for this project in January, 1987. The U.S. version of the proposal was ultimately funded in 1988, but various logistical difficulties (including the unavailability of the French MCS equipment in the Pacific during 1988, the retirement of the R/V *Conrad* in 1989, and the subsequent lack of MCS capability in the U.S. academic fleet until the R\V *Ewing* was launched in 1990) prevented simultaneous scheduling of both French and U.S. MCS



EW9103 Tahiti – Tahiti May 12 – Jun 9

vessels for the south-central Pacific. Finally in June, 1990, both French and U.S. agencies scheduled the expedition for May, 1991.

In December, 1990 the U.S. co-P.I.'s (McNutt, Detrick, and Mutter) met with French counterparts (Francheteau, Patriat) at IPG in Paris and at IFREMER in Brest to work out the logistics of the 28 days of two-ship work, including ship-to-ship communications, navigation, and exact placement of survey lines. At that meeting, both the French and U.S. P.I's first learned that the French vessel scheduled for this work, the N/O *Noroit*, had an endurance of only 15 days on account of her inability to take on a full complement of fuel when carrying the MCS streamer. Several options were discussed in Brest for how to deal with this problem, but it was not finally resolved until later in January when the French ship operators (IFREMER) arranged for a fuel barge to *rendez-vous* with the *Noroit* in the Marquesas to refuel the ship midway through the program.

The final problem that had to be resolved was the very tight schedule for shipping the French MCS streamer at the end of the Polynesian program to the Indian Ocean for another seismic program being conducted by Xavier Le Pichon. Delays in the *Ewing* schedule made it appear that there would be insufficient time to get the streamer to Mauritius. The problem was solved when the French were able to arrange for the streamer to be freighted to Columbo in time for the expedition. Le Pichon graciously agreed to begin his expedition from Columbo, rather than Mauritius.

Apparently IFREMER faced budget problems in early March, 1991, and made an internal decision on March 8 to cancel French participation in this program. Francheteau was alerted informally of the decision 5 days later by a colleague within IFREMER, but he was unable to gain enough support from outside IFREMER to get the decision reversed in time to ship the streamer from Brest to Tahiti for the expedition. In mid-March, after all avenues of recourse had been exhausted, Francheteau phoned McNutt with news of the IFREMER decision. This call was followed up on March 21 by a fax from Keranflec'h to Michael Rawson at Lamont explaining that the *Noroit* would not be participating in the program. At the time the *Ewing* sailed from Tahiti on May 12, neither the P.I's or NSF had received any official communication from IFREMER concerning their decision.

The U.S. P.I.'s considered a number of options for compensating for the loss of the French ship. The velocity information to be supplied by the Expanding Spread Profiles was considered essential to the success of the expedition. We checked into the availability of a second U.S. vessel, such as the *Washington, Moana Wave,* or the *Lee.* Scheduling of a second U.S. ship proved to be less of a problem than trying to find an MCS streamer for the vessel. We also examined the possibility of putting the seismic source, rather than receiver, on the second ship, but also found it impossible to provide sufficient compressor capacity to deliver a source volume capable of penetrating the thick volcanic crust beneath the island chains.

We next examined the possibility of using ocean bottom hydrophones (OBH's) or seismometers (OBS's) to provide the large source-receiver offsets required to obtain velocity information. It was not possible to ship any OBS or OBH equipment to Tahiti in time for this leg. Because the *Ewing* was engaged in two-ship OBS work with the *Washington* during the month of April, we pursued the possibility of transferring the OBS's and their support equipment from the *Washington* to the *Ewing*. The ships were scheduled to return to different ports (the *Ewing* to Tahiti and the *Washington* to Manzanillo), and therefore the transfer would have to be done at sea. The chief scientists of the two ships, after much deliberation, determined that such a transfer would be impractical.

Fortunately, the *Ewing* would be returning to the Marquesas area in late September-October, 1991 for a Hydrosweep survey of the Marquesas Fracture Zone (McNutt, Natland, and Kruse, co-P.I's). This scheduling provided the opportunity to postpone the seismic refraction part of the program until later in the year when there would be time to ship OBS equipment to one of the *Ewing's* ports-of-call. Therefore, one week of ship time was subtracted from EW 91-03 and added onto EW 91-06. The *Ewing* was scheduled to pick up the Scripps van and OBS equipment in Valpariso, Chile at the end of EW 91-04. The equipment will then be carried to Easter Island during EW *91-05* where it will then be available for one week of seismic refraction work during EW 91-06.

This cruise report contains information on only the seismic reflection part of this experiment. The seismic refraction portion is covered in the cruise report from EW 91-06.

2.0 Tectonic Setting

The Society, Marquesas, and Tuamotu island groups are three of the more prominent NW-SE-trending island chains in French Polynesia (Figure 1). Of the three, the Tuamotus are presumed to be the oldest, approximately 45 Ma based on $^{40}Ar/^{39}Ar$ dating of limited basalt samples recovered from the extreme northwestern end of the plateau *[Schlanger et aI.,* 1984]. The Society and Marquesas are both late Tertiary volcanic chains with well-documented age progressions getting younger to the southeast

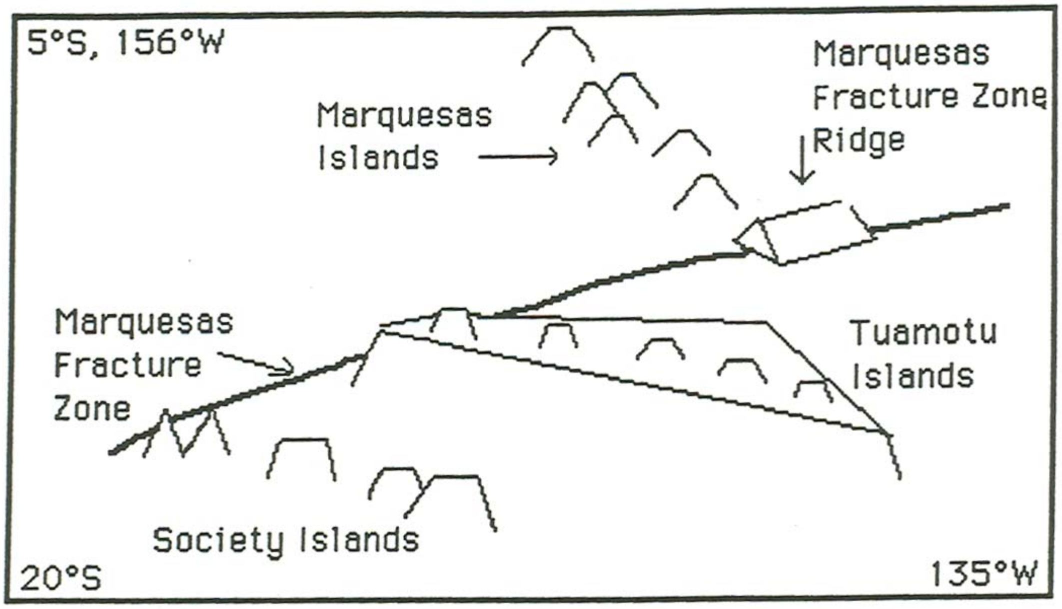


Figure 1. Schematic figure showing the location of prominent tectonic features in French Polynesia surveyed during this cruise: the Marquesas Islands, the Marquesas Fracture Zone Ridge, the Tuamotu Islands, and the Society Islands.

Both the Tuamotu plateau and the Society Islands lie south of the Marquesas Fracture Zone (MFZ) on a broad (5000 km E-W by 2000 km N-S) regional depth anomaly termed the South Pacific Superswell by *McNutt and Fischer* [1987]. The distinctive features of the Superswell are age-correlated depth anomalies (relative to the standard 125-km-thick plate model) that reach values of 1 km on old lithosphere, low phase velocities for Love waves in the period range 40 to 125 sec, elastic plate thicknesses less than 15 km regardless of lithospheric age, and a broad regional negative geoid anomaly. The depth and Love-wave anomalies are both consistent with a thinner lithosphere (75 km) beneath the Superswell. The geoid anomaly indicates that the thinner lithosphere is dynamically maintained by broad mantle upwelling in a shallow low-viscosity zone beneath the Superswell. The low elastic plate thicknesses remain unexplained as the amount of plate thinning necessary to raise the geothermal gradient sufficiently to produce a 15-km-thick elastic plate is greater than that required by depth, Love-wave, and heat-flow anomalies.

The Marquesas Islands lie just north of the MFZ on what is presumed to be normal oceanic lithosphere. Except for the Marquesas swell that surrounds the island chain, the depth-age relationship in this area of the Pacific is well explained by the 125-km-thick plate model. Furthermore, statistical studies of seamount abundance demonstrate that the MFZ marks a sharp boundary between an abnormally high seamount production rate on lithosphere of the Superswell to the south as compared with that for the lithosphere to the north *[Bemis,* 1990].

2.1 *The Tuamotus*

The Tuamotu Islands sit on a broad plateau 300-500 km wide that extends for 1500 km to the southeast from the MFZ. The edges of the plateau rise steeply to 2000 m from abyssal depths of 4200 m. All of the islands are coral atolls which surmount individual volcanic pedestals rising above the plateau. Plate reconstructions suggest that the plateau formed between 70 and 35 Ma by one or more near-ridge hot spots. However, there is little direct geophysical evidence to support this model, and the relationship of the islands to the plateau is still unknown. DSDP site 318 drilled Tertiary pelagic sediments in the saddle between Rangiroa and Ahé, but did not penetrate basement.

The existence of the stations of French Polynesian Seismic Network on Rangiroa Atoll, near the northwestern part of the plateau, to monitor nuclear test blasts on Mururoa Atoll, near the southeast edge of the plateau, provides information on its crustal thickness and seismic structure. *Talandier and Okal* [1987] present a 4-layer model for the plateau as shown in Figure 2. The total crustal thickness from the sea surface is about 31 km. Beneath the islands themselves, the coral caps are approximately 2 km thick with velocities of 3.3 km/s, and the basalt layer thickens to 4.5 km.

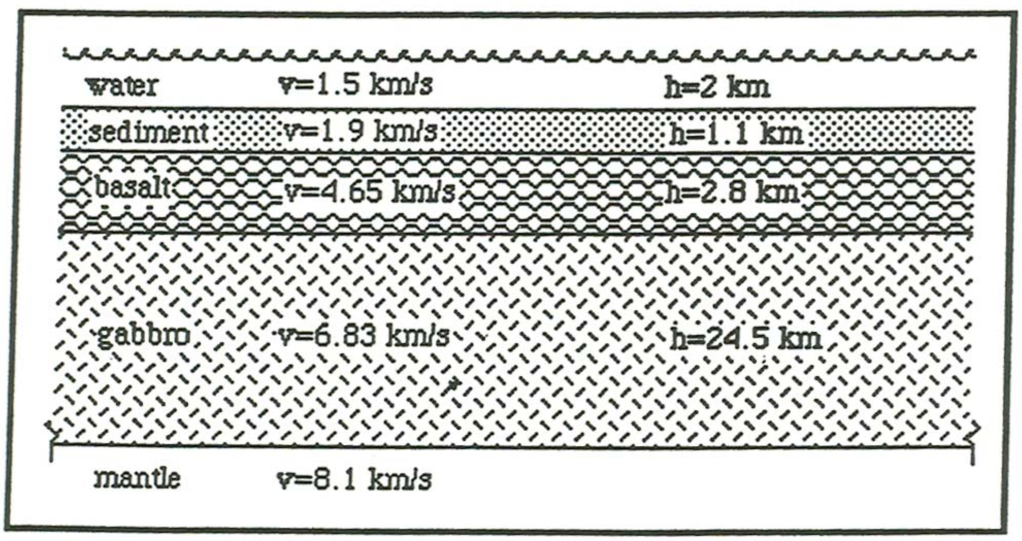


Figure 2. Model for seismic velocities and layer thicknesses beneath the Tuamotu Plateau from *Talandier and Okal* [1987].

Our seismic profile through the Tuamotu Islands is the first MCS profile across the chain. It places better constraints on the crustal structure of the plateau and the structural relationship of the islands to the plateau pedestal. The seismic data provides a geophysical context for interpreting the facies drilled at site 318.

2.2 *The Societies*

The Society Islands range in age from 14 Ma at the northwest end of the chain near the MFZ to zero age at the Teahitia-Mehetia seismic zone 70 km southeast of Tahiti. The Society swell rises approximately 0.5 km above the regional depth of the Superswell. Geoid modeling places the compensation depth of the swell at about 45 km, suggesting that the 75-km-thick lithosphere of the Superswell is even further thinned locally beneath the islands by the Society hot spot. Flexural modeling constrained by the satellite geoid and the location of islands uplifted on the flexural arch of Tahiti yield an elastic plate thickness of about 15 km, much less than the 25-30 km for the Pacific lithosphere of similar age flexed beneath the Hawaiian islands.

Some seismic constraints on the structure of the Society Islands already exist from French and German experiments. *Talandier and Okal* [1987] obtain a seismic velocity model from nuclear shot blasts recorded at stations on and near Tahiti. Their model is summarized in Figure 3. Felix Avedik collected a number of short, multichannel seismic profiles near the young end of the Society chain. However, his source volume was much smaller than what is used for this expedition, and his streamer had fewer channels. Therefore, the data set collected during EW 91-03 is far superior for investigating the deep structure of the Society Islands. The refraction data recorded during a French-German two-ship experiment using ocean bottom hydrophones should prove invaluable in interpreting the reflection data collected during this expedition.

The seismic reflection data we collected across the Society chain will be used to test gravity models of flexure of the lithosphere and map the deep structure of the island chain. The results can be directly compared to such information from an MCS survey of the Hawaiian chain to compare the styles of volcanism and mechanical response of the lithosphere on normal lithosphere versus thermally anomalous Superswell lithosphere.

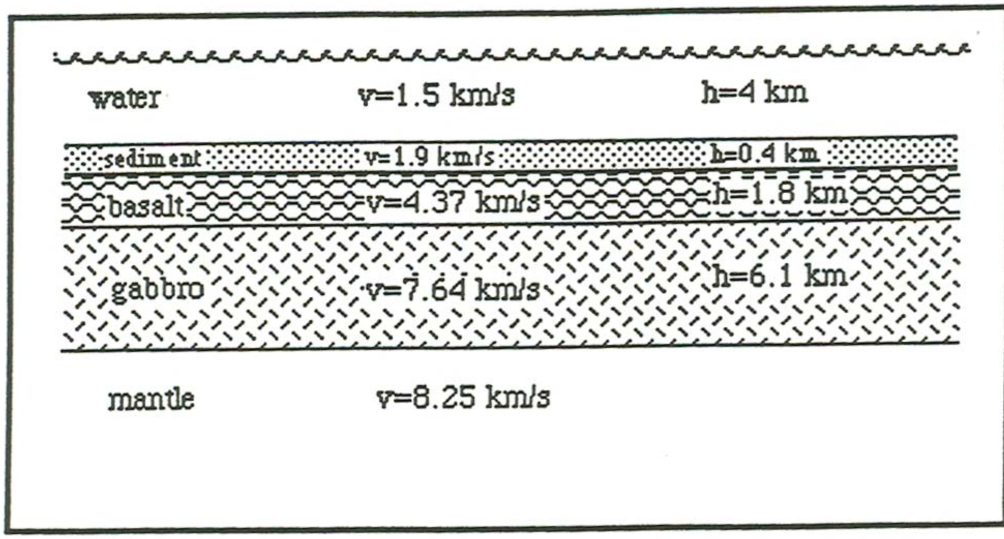


Figure 3. Seismic velocity model from *Talandier and Okal* [1987] for the crust surrounding the Society Islands. Locally beneath the island of Tahiti, the only change they propose to this model is that the basalt layer thickens from 1.8 km to 5.6 km.

2.3 *The Marquesas*

The Marquesas Islands are a short chain of volcanoes which range in age from 5.3 Ma for Eiao at the northwest end to 1.6 Ma for Fatu Hiva at the southeast end of the chain. They appear to be a classic hot spot chain, much like the Hawaiian and Society chains, except for the fact that the duration of volcanism spans a very short interval in time, there is no known active volcano southeast of Fatu Hiva, and the azimuth of the chain lies 30° further north than other coeval Pacific chains. *McNutt et al.* [1989] suggest that all of these anomalous features can be explained as the consequence of a plate with a preexisting zone of weakness oriented northwest migrating to the north-northwest over a 275-km-wide hot spot. They predict that zero age is presently located along the Marquesas Fracture Zone ridge, not to the southeast of the island chain. Seismic lines from this expedition will reveal whether the hypothesized structural weaknesses can be detected in the deep roots of the volcanoes.

Both the Marquesas and Society island chains are unlike the Hawaiian chain in having no topographic moat surrounding the islands. Rather, the Marquesas are the type locality of the "archipelagic apron", a smooth pediment dipping gently away from the volcanic pedestals for at least 250 km, burying any flexural moat and the preexisting topography of the seafloor. The thickness, structure, and composition of archipelagic aprons is poorly known at present, but results from this expedition should place strong constraints on its thickness, relationship to the volcanoes, and velocity structure.

The only geophysical information concerning the Marquesas, other than satellite geoid data which has particularly poor resolution in this area, was collected on expedition *Crossgrain 2* by the R/V *Thomas Washington* in 1987. The gravity data from that expedition shows clearly the flexure of the lithosphere beneath the islands and their apron, but the single-channel seismic data was not able to penetrate the thick, high reverberatory apron. Limited sonobuoy refraction data suggests that the apron may be as thick as 2 km near the base of the volcanoes. Based on analysis *of* the *Crossgrain 2* data, the elastic thickness of the lithosphere appears to be greatest (30 km) at the northwest end of the chain, dropping to about 17 km in the center of the chain, and falling further to about 10 km or less at the southeast end *[Filmer*, Ph.D. thesis in prep.]. This variation is inconsistent with models of lithospheric thinning by the hot spot, viscoelastic relaxation of the elastic plate, etc., which would all produce variations in the opposite sense. This expedition collected additional gravity data and the seismic reflection data needed to verify or refute this surprising result

3.0 Experimental Methods

The principal tool for exploration of the deep structure of the island chains was multichannel seismic data, supplemented with gravity, magnetics, and 3.5 kHz bottom profiling. Because this was only a one-ship experiment following the cancellation of the French vessel, we collected conventional CDP data which provides an image of the subsurface in terms of two-way travel time to reflecting layers as a function of distance along track. To convert the time section to a depth section, we need velocity control. Some velocity control will be obtained from 30 sonobuoys launched during our CDP profiling, existing French refraction data, the OBS refraction experiment on EW 91-06, and analysis of CDP gathers from the present leg.

For the CDP profiling, we deployed 20 airguns with a combined source volume of 8385 cu. in (Figure 4). Initially, the guns fired every 20 seconds, but in the later part of the leg the firing rate was reduced to 19 seconds to compensate for the greater speed of the ship required to keep the streamer from sinking. The streamer was configured in 25 m group lengths for a total length of 3.7 km. The DSS recording system digitally sampled each of 148 channels every 4 milliseconds for 16 second records. Later in the expedition we reconfigured the system to write 15 second records in order to avoid system crashes thought to be caused when there was insufficient time to dump the buffer to tape between shots.

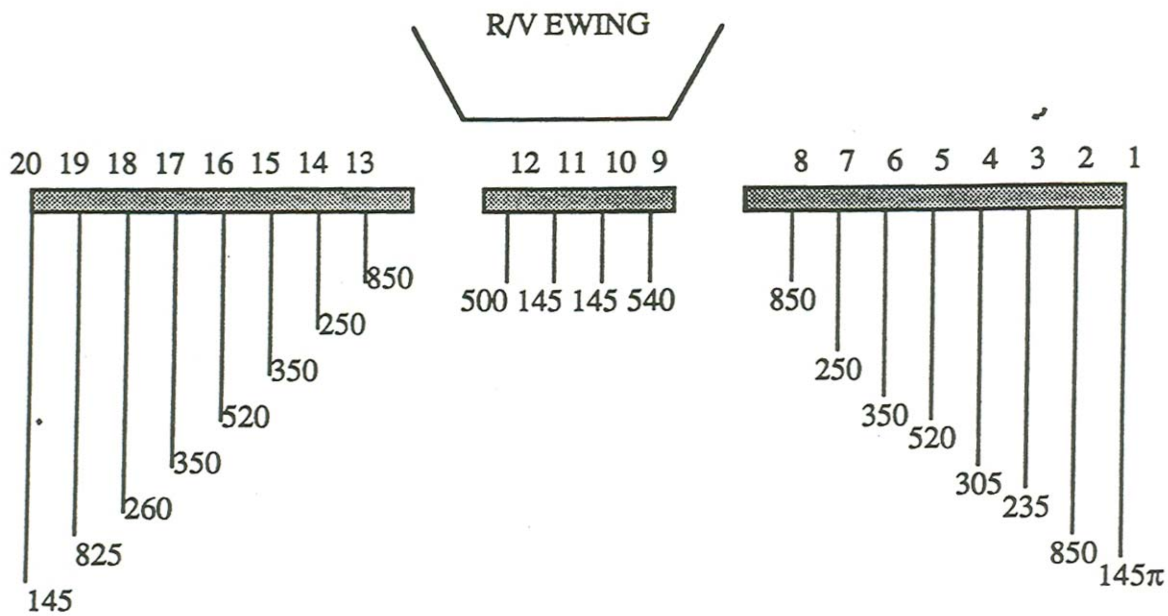


Figure 4. Schematic diagram showing the *Ewing*'s gun array. Guns are numbered consecutively from starboard to port, with the numbers at the bottom giving source volume of individual guns in cubic inches.

Two gravimeters were available for use: a Bell BGM-3 gravimeter and a KSS-30 gravimeter. Reports from the previous leg EW 91-02 were that the Bell gravimeter was not operating reliably and was subject to significant drift. The KSS-30 appeared to be operating quite well.

4.0 Data Acquisition

12 May (Sunday) - At 1000L the R/V *Maurice Ewing* sailed from Papeété, Tahiti. The departure was delayed two hours from the original schedule of 0800L on account of engineering work that needed to be completed in port. Such work included welding steel plates over bow thruster tunnels in an attempt to reduce noise in the Hydrosweep acoustic system. French holidays on two of the days in port hampered preparations for departure by making it difficult to arrange delivery of shipments for the *Ewing* held in customs.

Weather was good and seas smooth at the time of departure. Winds from the north at 10 kts. Not a single case of seasickness in the entire scientific party, despite the fact that several members were making their first trip. After the first fire and boat drill at 1520L, we deployed the magnetometer. Underway watches began at 1900L after a brief orientation by the Science Officer, Joe Greer. Began logging 3.5 kH, Bell gravimeter, KSS-30 gravimeter, and magnetometer data.

13 May (Monday) - We estimated the transit to the point for deploying the streamer west of the Marquesas to take 2.3 days of ship time. The Hydrosweep tests are being carried out by Chayes/LDGO and Schlumberger/SSI during transit. In noise tests on the system, they found large spikes in the transducer output. The noise is dependent on ship speed, becoming a very serious problem at speeds approaching 10 kts.

14 May (Tuesday) - Hydrosweep tests continued through the night.

At 0830L, we began deploying the streamer. The streamer was deployed by 24OOL. We found it necessary to replace one bad streamer section and its cannister (#24) where seawater corroded the connector. Patched a number of holes in the streamer and refilled drained sections with oil. Had to drain some oil from other sections that appeared overinflated on account of thermal expansion of the oil in the warm temperatures of the tropics. Deployed a full 4 km of streamer, but after deployment found that the cannisters on the last three sections were not responding properly. We suspect that can #3 failed; cans #1 and #2 may be functioning properly, but their data cannot be relayed to the ship through can #3. We have no more spare cannisters. Continued with a 3.7 km streamer and 148 channels, steaming at 4.8 Jets.

15 May (Wednesday) - Deployed 20 airguns in the early morning hours. Manuvered to position for line Marq 1 (NW end of chain between the islands of Eiao and Nuku Hiva), and began shooting line at 0800L. Despite last-minute course changes necessitated by the delay in getting all seismic systems online, Marq 1 began exactly on target, on the last abyssal hill lifted above the archipelagic apron by the flexural arch surrounding the islands. Numerous unexplained crashes of DSS system required resetting it. Otherwise, the data looked fine. Dave Caress has succeeded in reading shot tapes on the Sun computers and is plotting shot gathers for some off-line quality control and data analysis using SIOSEIS provided by Paul Henkart.

16 May (Thursday) - Continued shooting line Marq1. We launched Sonobuoy #1 over the deepest part of the moat at about 0830L and recorded several refracted arrivals. Preliminary analysis of the sonobuoy data is shown in Figure 5. Nuku Hiva was visible off the starboard by mid morning. Eiao was seen off the port by mid afternoon. The gravity profile west of the islands displays a clear flexural moat and arch.

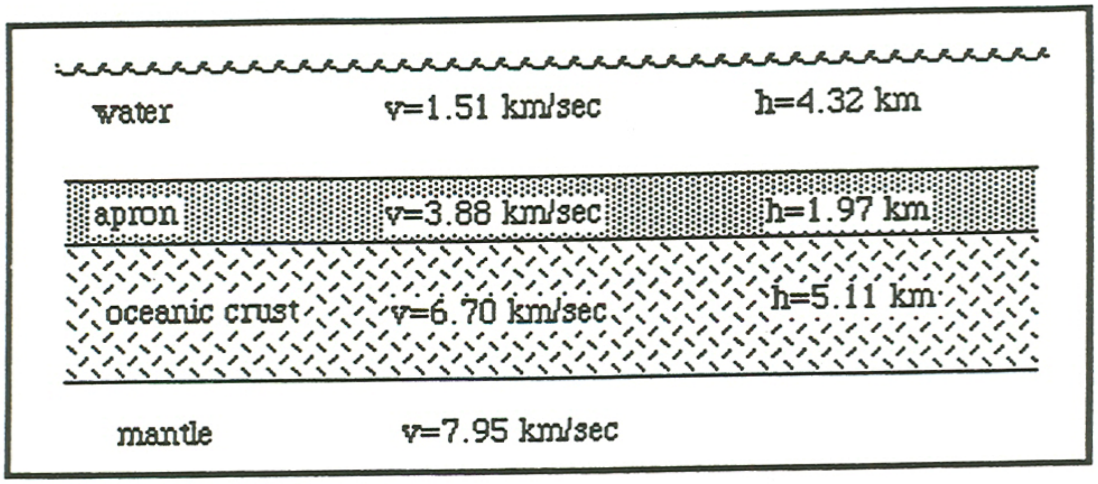


Figure 5. Preliminary interpretation of refracted arrivals recorded on Sonobuoy #1, located in the deepest part of the Marquesas moat on the western flank of the horthernmost cross-section surveyed through the chain, between Eiao and Nuku Hiva.

17 May (Friday) - Continued on line Marq 1, despite many more DSS system crashes. Most crashes were recovered within two shots or so. Others were more difficult to recover from, and we lost at times 20 minutes or more of data. Chief Mate Ian Young completed construction of the expedition swimming pool. Launched Sonobuoy #2 (in ocean, not pool) just before dinner.

18 May (Satuday) - Ended line Marq 1 at 10 am when well over crest of flexural arch. Began line Marq 2. Shut recording system down in midaftemoon to attempt to track down source of DSS system crashes, which have become more frequent. System back up by 1800L. System still hangs up after running for 1 to 3 hours. Reduced record length to 15 seconds while retaining a 20 second shot rate, which solved the problem.

Chayes and Schlumberger find several damaged boards in the Hydrosweep system, but only succeed in getting reasonable data when the airguns are off and the ship's maserator pump is off. The pump is immediately adjacent to the sonar array.

19 May (Sunday) - Continued survey of line Marq 2. Launched Sonobuoys #3 and #4 to record velocity structure of "normal" oceanic crust. On far side of flexural arch. Preliminary interpretation confirms that area has velocity structure of nonnal crust. Total crustal thickness is 5.0 km overlying mantle with assumed velocity 7.5 km/sec. Turned onto line Marq 3 at 2030L.

20 May (Monday) - Continued survey of Marq 3. Found well developed apron, narrow flexural moat. Had to retie Chinese finger that holds streamer to the ship because the previous one was becoming frayed. Readied another 50 m streamer section from van on A deck.

21 May (Tuesday) - At dawn, Fatu Hiva was abeam on the port and Hiva Oa, Tahuata, and Montane were abeam off the starboard. Launched Sonobuoy #5 into the flexural moat just west of the islands at about 10 am. Finished survey of line Marq 3 at 2100L. Tuned south to run parallel to, but just north of, the fracture zone (Marq 4).

22 May (Wednesday) - Launched Sonobuoy #6 at about 10 am. Very rough topography SW of islands, so unlikely that it will give good data. Same problem with Sonobuoy #7 launched at 2050L. Through the night, fail to find smooth enough slopes on the lava carapace to get any good refraction data.

23 May (Thursday) - At 0400L, turned to make run along fracture zone ridge (Marq 6). Average elevation of rounded summit is 2500 m, with frequent volcanic cones rising to 1900 m. Launched sonobuoys 9 and 10 along the ridge. Turned south to survey 40 Ma crust on the Superswell south of the FZR (Marq 7 and 8).

24 May (Friday) - Launched Sonobuoy lion abyssal hill fabric of the Superswell. Finished survey south of FZ. Turned north (Marq 9) towards the start of the final cross-section through the central Marquesas.

25 May (Saturday) - Continued north to start of Marq 10. Succeeded in randomizing shots in an attempt *to* reduce the amplitude of high-order water multiples. Filled last spare streamer section with oil. Have had no MCS system crashes wince change to 15 second records.

26 May (Sunday) - Continued north to start of Marq 10. Began shipboard seminar series. McNutt led off with overview of science objectives.

27 May (Monday) - Began survey of Marq 10. This line passes through the center of the chain and will be the location of the OBS experiment during EW9106. Sonobuoys are to be launched at 25 km intervals to complement OBS work. Launched sonobuoys 12 and 13 along proposed path of OBS experiment in October.

28 May (Tuesday) - Continued survey of Marq 10. Continued to launch sonobuoys 14 through 23 along OBS line. Had recording failure on Sonobuoy 19 on account of trying to use the two receivers to record two different buoys. Sonobuoy 21 ceased transmitting after only 10 minutes. Suspect that it might have become caught in streamer. Continued shipboard seminar series with John Mutter giving overview of seismic acquisition system.

29 May (Wednesday) - Continued survey of Marq 10. Launched sonobuoys 23-25 to complete refraction profile within islands and to the east of the chain. Al Karlin lectured on compressors and John Dibernardo on airguns.

30 May (Thursday) - Continued survey of Marq 10. John Mutter, Carlos Guiterrez, and Joe Greer lectured on streamers, birds, and the DSS recording system.

31 Ma.y (Friday) - Completed survey of Marq 10. Began steaming towards Tuamotus.

1 June (Saturday) - Reached Tuamotu plateau in late evening. Carolyn Zehnder and David Caress lectured on analysis of reflection and refraction data.

2 June (Sunday) - Surveying Tuamotu Plateau. Bruno Comaglia lectured on the tectonics of the south Pacific. Firing rate of guns changed to 19 s to help compensate for fast velocity over ground caused by following current. Shorter pop rate leads to several system crashes through the night.

3 June (Monday) - Turned onto line Soc 1 at about 6:30 am. Lab mislabels line as Tua 2.

4 June (Tuesday) - Continued survey of first line through Society Islands. Seas got rough as we moved south, and high winds persistently blow from the SE. McNutt lectured on the results from gravity modeling of expedition data from the Marquesas Islands.

5 June (Wednesday) - Chayes lectured on the Hydrosweep system and how all of the computers and logging activities are interconneccted throughout the ship. Turned onto line Soc2 (labeled as Soc 1 because Socl was labeled Tua2) at about 2130L. Returned to 20 second shot spacing when speed slowed. Gun failures began to increase over past few days.

6 June (Thursday) - Turned onto line Soc 3 (labeled Soc2 by the lab) at 1206L. Seas remain high. Sufficient speed to keep the streamer from sinking caused many high tension alarms. Decision made at 1430 to recover airguns, streamer, and cease MCS activities rather than risk losing or damaging streamer. Streamer recover initially progressed slowly because we had to speed up ship to bring tail sections of streamer to surface, and then slow down to reel it in. About 1630L we launched the Avon with the 2nd and 300 mates and an AB to put a sea anchor on the tail buoy in an attempt to put more drag on the streamer to prevent the tail sections from sinking. Operation completed about 1830, and then recovery progressed smoothly. Several sections of the streamer, particularly those near the tail that had been sinking for the past week, had leaked badly such that they were mainly filled with sea water. The leaks were mostly attrtbuted to shark bites. Most of the bites were near cans, leading us to suspect that the shiny metal cans were attracting the sharks. A number of the birds near the tail section were also not operating, and had not responded to the lab commands to come to the surface. Tail Buoy secured about 2330L. Ship turned to reoccupy position at 1430L just before streamer recovery in order to finish the line for gravity even though MCS data would not be acquired.

7 June (Friday) - Continued gravity line northeast towards Tahiti. Finished gravity line with Tahiti off port at 1600L. Began several days of Hydrosweep testing. Robinson lectured on the data logging and reduction process on board ship.

8 June (Saturday) - Hydrosweep testing continued. Moved guns up to van on A deck.

9 June (Sunday) - Completed Hydrosweep testing in late morning. Made ammgements with port authorities to dock in late afternoon, 16 hours earlier than expected.

5.0 Preliminary Results

We collected over 3500 km of MCS data and launched 31 sonobuoys during the course of the expedition. We completed three long MCS profiles through the Marquesas Islands, one line along and one across the Tuamotu Islands, and one through the Society Islands. We also collected MCS data along the Marquesas Fracture Zone Ridge and on typical abyssal hill fabric of seafloor both north of and on the Superswell. Except for some detailed French/German work in the vicinity of Tahiti, this data set comprises the first MCS observations in these areas. Preliminary low-fold stacks made using SIOSEIS on the Sun computer suggest that the Moho and the internal structure of oceanic crust should be imaged. Some dipping reflectors in the shallow crust have already been resolved. Detailed interpretation of the MCS results will be available after processing at Lamont.

Interpetation of some of the sonobuoys was completed on board ship using JDSeis operating on the Sun computers. These results are attached as Appendix 1. In general, away from the island chains the crust has a velocity profile typical of normal oceanic lithosphere. The pelagic sediment layer appears to be approximately 200-300 m thick everywhere except where covered by recent flows or apron seidments. The aprons of the islands consist of high velocity material at relatively shallow depth, which is consistent with the gravity interpretation that the flexural moats are filled with high density volcanic flows, volcanic turbidites, and/or volcaniclastic sediments. Where apparent as a distinct layer (vp=3.5 to 5.5 km/s), the apron sediments are approximately 0.5 to 1.5 km thick, although the gravity data suggests that the surface of the preexisting seafloor is actually buried at much greater depth.

Gravity interpretation for the three profiles through the Marquesas Islands is attached as Appendix 2. The best-fitting elastic plate thickness for all three profiles is uniformly 17 ± 2 km assuming a' crustal density of 2650 kg/m3. If the density is reduced to 2500 kg/m3, the best-fitting value for Te increases to 20 km, but the fit of the gravity to the peaks over the volcanic ridge is not as good. Assuming high crustal densities would allow slightly lower values for T e, but again the fit over the island peaks is degraded.

Helen Webb and Deborah Dixon interpreted the 3.5 kz data throughout the Marquesas Islands. They mapped the extent of volcanic flows, apron sediments, and abyssal hill outcrops. Their results are consistent with an evolutionary model for formatian of the islands chain in which diffuse volcanism becomes gradually concentrated into a few central volcanoes. The apron gradually thickens with time, but is already well developed just north of Fatu Hiva. Flexure of the lithosphere is important in controlling the extent of the apron.

6.0) Comments and Recommendations

General

The *Ewing* is an extremely comfortable and well-equipped ship for MCS work. We received excellent cooperation from the Captain and crew concerning all aspects of the science operations, and it is clear that they have a "science first" attitude. Several members of the crew were interested enough in the science operations to regularly attend the science lectures on board. Others were frequent visitors to the lab to check on the science operations and the latest research results. For the most part, relationships between the scientist and crew were very congenial. Some members of the science party felt quite strongly that this is the best crew on any U.S. academic vessel. The engineers worked extremely hard to keep the compressors up and running without interruption for the duration of MCS work. Even the food was superb.

From the standpoint of facilitating onboard data reduction and interpretation, several improvements could be made. Given that the *Ewing* typically carries a scientific party of 15 to 20 people with with time available to begin the immense task of digesting the data collected on the expedition, some additions to the science facilities on board would allow those scientists to make the best use of their time.

For example, it was disappointing to find that the *Ewing* had no semblance of a science library. At a minimum, space should be found (perhaps in the seldom-used Science Office on the A deck) to house a set of *DSDP/ODP* volumes and a set of *The Sea.* Some basic reference texts in physical sciences and oceanography would also be helpful. Some scientists may be talked into donating some back issues of journals, such as *JGR,* which are taking up too much space on their bookshelves. The DSDP volumes, for example, are likely to contain basic background information for any area visited on a *Ewing* cruise, and the drilling results can be invaluable for estimating sediment thickness, age, physical properties, and lithology on seismic cruises. One of the crew members even suggested having a collection of reprints reporting the scientific results from Lamont expeditions. Columbia University Press has even agreed to donate books for use on the ship.

In addition, a considerable amount of time was spent in port and during the first few days of the leg setting up computers that the P.I.'s had shipped to Tahiti and wiring them to existing peripheral devices, such as printers and tape drives. The time taken up by such activities would have been even longer were it not for the fact that Suns and Macintoshes had been used on the previous leg. Given the cost of transporting such basic equipment and the time necessary to connect it up on board, we highly recommend that Lamont consider providing on board Sun equipment for off-line data processing and a Macintosh for preparing cruise reports, drafts of manuscripts, etc. These two computer systems are widely used at Lamont and at most other academic institutions likely to use the *Ewing.*

Temperature in the main lab is very uneven. The racks of tape drives, recorders, and computers, which generate most of the heat, are all in one spot. In an attempt to keep the lab cool enough to prevent overheating near the racks, the remainder of the lab was uncomfortably cool for scientists working in the lab, particularly those who had packed for a tropical cruise. While the ship is in the yard next time, some thought should be put into how to redistribute the air conditioning in the lab.

It would also be useful to have a few more comfortable chairs in the lab. With two Macintoshes set up, two Sun computers, the MassComp terminals, plus the regular underway watch activities, were constantly shuffling chairs around the lab.

MCS-Specfic

During operations on EW 9101, 9102, and 9103 approximately 90 days of MCS data were acquired from the R/V *Ewing* in a variety of different styles and environments ranging from reconnaissance of the continental margin of Antarctica, detailed study of portions of the East Pacific Rise involving grids of relatively closely spaced, short lines, and an investigation of the Marquesas and Society Islands involving several very long transects. Weather conditions during these studies ranged from flat calm to Beaufort 9, and water temperatures ranged from -1.4°C to 28.6°C. The hydrophone array was configured as 3 km, 120 channels and 4 km, 160 channels. The same gun array comprising 20 guns for a total volume of 8385 cu inches, fired at a 20 sec rep rate was used for most of the work. During the East Pacific Rise program several other gun array configurations were used - alternate halves of the array were fired at 20 see to obtain a 4200 cu inch array volume at a 10 sec rep rate; six of the 20 guns for a volume of 2300 cu inches were fired at 40 see rep rate, and the total volume was also fired at 60 sec. These changes were easily effected.

The present staff levels appear adequate to maintain the equipment in its present configuration. We support the request of the Chief Engineer for an additional man in the engine room for compressor work on MCS legs - getting the compressors in shape for EW9102 following their use on EW9101 was a major scramble that involved pulling staff from many other areas including the galley. The lab watch can be handled, by one watchstander, even if Hydrosweep is also running.

In general the operations were very successful and have shown that the R/V *Ewing* is a highly suitable platform for MCS operations. During the Antarctic study the streamer was deployed continuously for approximately 32 days; the longest period of continuous operation we have attained with any multi-channel streamer. The vessel presently deploys the largest MCS system available on an academic platform anywhere in the world and is clearly capable of routinely managing this, and potentially much larger capabilities. The following comments and suggestions are based on the successful experience of the last three cruises and represent improvements that would allow the present capability to be operated in a more effective manner, and allow for development beyond the present system. No priority order is intended.

• At least 60 hrs should be included for **routine** deployment and recovery of the 4-km hydrophone array. .

• The 4 km streamer suffers frequent damage when wrapped onto the winch following deployment in a warm water environment due to softening the jacket. All cannisters, inter-connects and bird collars were wrapped with rags intended for use in the engine room in a very rudimentary and time-consuming process. This may have somewhat reduced the problem but did not prevent the jacket from being punctured in many places on the inner wraps where cannisters and other metal parts of the streamer lay against the soft jacket. A permanent solution to this problem must be found by maintaining a supply of re-useable, high density padding material that can be laid under the streamer sections during recovery.

• The tailbuoys now in use seem, at last, to be quite suitable as a passive device. The buoy is seldom visible on radar and some improvement in radar recflectivity or an active system is needed. Visual location of the tailbuoy is difficult, but considerably improved if a Norwegian buoy is towed behind the tailbuoy. This would also act to give flotation in the event that the tailbuoy were damaged. This should be standard practice. The suitability of these tailbuoys to carry sufficient batteries to power active systems like GPS sets is not proven.

• The 4-km streamer is very weather sensitive; conditions as moderate as force 4 will cause towing in proper trim to become unmanageable and lead to unacceptably high stresses on the streamer. Towing would be improved if a new deck leader was purchases to replace the one that failed on EW9101. Stress may be reduced if a second stretch section were added. Even with these changes the 4-km array is likely to be difficult to safely manage in areas where poor weather is anticipated.

• The "true" critical stress for the streamer cannot be known because it is only as strong as its weakest component and this cannot be determined in advance. Hence critical stress is not known until its too late and the streamer has broken. We operate on what is probably a conservative critical stress of 4000 lbs and this typically corresponds to stresses induced by sea states that make the streamer trim difficult to control. Digicon is understandably reluctant to give firm numbers on critical stress (maybe due to implied liapility), but some attempt needs to be made to establish typical field operating stress levels so that we know safe operating parameters.

• Ship handling is an important factor in proper operation of all the towed equipment, especially the streamer. The bridge now has available displays of streamer stress, and depths (repeated from lab monitors), an alarm that sounds at a pre-set streamer stress, and a monitor of back deck operations. The ship's officers are developing the skills necessary to make turns and maintain proper speed control for safe operation of the towed equipment. To allow the officers to carry out this task in a proper manner the following are strongly recommended. The displays on the bridge need to be re-positioned to be integrated into the starbord side consol (they presently sit on top of the consol and obstruct vision on that side). The tiny tachometer that reads the revolutions on the prop needs to be replaced with a large-format digital display - speed adjustments of 0.5 RPM can be critical to towing stress in poor weather conditions and are essentially impossible to make with the present display. The way in which turns are made is critical to the safety of all towed equipment The officers are presently instructed to make turns at 5° per minute, but there are numerous ways in which this can be achieved. Instantaneous rates of heading change often occur at much greater than the required 5° per minute causing the streamer to be sharply bent across the vertical posts that protect the stern A frame leading to sharp increases in the towing stress. At minimum this invites damage to the deck leader and tangling of the guns, but has considerable potential for causing the streamer to be broken pear the head section and lost. Any damage would likely not show mediately but develop during later legs. The present steering stand does not have the facility to make turns at a pre-determined turn rate. While I understand that the steering stand is a recent installation it should be upgraded as soon as possible to one that has the appropriate turning rate function.

• A great deal of streamer maintenance can be accomplished during operations from a suitable work boat. This avoids the inefficient and potentially harmful operation of retrieving the array for relatively minor repairs. The present rescue boat was used on EW9103 to attach a sea anchor to the tail buoy during retrieval of the array and accomplished that task reasonably well. However, it would be difficult to achieve very much more from this craft since it is unlikely that it could safely support the weight of a streamer section if it were necessary to bring it out of the water for inspection or, for instance, the replacement of a faulty depth control bird. If there are plans to replace the present rescue boat, consideration should be given to a design that would make it suitable as a work boat. If not we should seek to acquire a suitable work boat; a new one is not necessary.

• The on-board seismic processing and analysis system that was available on a Sun based system using SIOSEIS software during EW9101, 02 and 03 proved to be very useful. The system produced a stack using portions of the streamer and an assumed velocity model a few hours after acquisition, and a constant-velocity F-K migration a few hours following that. Simple shot records for QC were available a few minutes after removal of a tape from the Telex drives so that decisions based on data quality could be made in a very timely manner. While a truly on-line stack would be most useful, the ability to examine portions of the data that were critical to cruise planning was extremely beneficial. The system made use of readily available Sun hardware with associated tape drives and disk storage devices. After the change is made to cartridge storage devices on the DSS 240 a similar system could be created with cartridge drive input since these are SCSI devices which can be provide relatively easy input to the Suns. It seems most appropriate to use Sun hardware since we have extensive experience with these at Lamont, and probably install SIOSEIS, a basic version of Sierra Seis which is available through the IRIS consortium, and a Sun-based version of JDseis. The combination of these packages would be very valuable for QC of all data types (the sm wiggle trace camera could be removed), display of data following simple processing and the velocity analysis of sonobuoys and ESP data, all of which allows for informed decision making at sea to maximize the scientific return from an MCS study.

Table 1

EW 91-03 Scientific Party

Marcia McNutt (MIT) and John Mutter (LDGO) - co-chief scientists
Joe Greer (LDGO) - Science Officer
Dale Chayes (LDGO) - Hydrosweep technician
Don Schlumberger (Seafloor Surveys International) - Hydrosweep technician
David Caress (LDGO) - scientist
Carolyn Zehnder (LDGO) - scientist
Anol Bhattacharya (LDGO) - scientist
Bruno Cornaglia (IPG, Paris) - scientist
Garrett Ito (MIT) - scientist
Helen Webb (MIT) - scientist
Deborah Dixon (Colorado College) - scientist
Carlos Guiterrez (LDGO) - MCS technician
Bill Robinson (LDGO) - computer systems manager
John Dibernardo (LDGO) - senior airgun technician
Ruben Smith (LDGO) - airgun technician
Ropati Maiwiriwiri (LDGO) - airgun technician

Line	Tapes	Reels	Files	Shot Points
Marq-1	001-004	105-108	0100-0391	012271-012563(?)
Marq-1A	005-013	109-117	0100-0844(?)	012579-013343(?)
Marq-1B	014-015	118-119	0100-0264	?
Marq-1C	016-021	120-125	0100-0552	? (includes 013590-013843)
Marq-1D	022-112	126-216	0100-7686(?)	013990(?)-021643(?)
Marq-1E	113-162	217-266	0100-4249	000033-004256
Marq-2	163-172	267-276	4250-5095	004396-005241
Marq-2B	173	273 (repeat of reel number 273)	5096-5135	005712-005771
Marq-2C	174-184	274-284 (repeat of reel numbers 274, 275, 276)	5136-6024	005772-006670
Marq-2D	185-201	285-301	6025-7454	006681-008109(?)
Marq-2E	202-207	302-307	6025-6359(?)	008221-008555(?)
Marq-2F	208-228	308-328	7000-8816	008580-010396

There are no tapes 229 and 230 / no reels 329-330

Line	Tapes	Reels	Files	Shot Points
Marq-3	231-332	331-432	7000-5853	010432-019291
Marq-4	333-375	433-475	5854-9654	020013-023813
Marq-5	376-384	476-484	5854-6651	023936-024733
Marq-6	385-401	485-501	5854-7325	025060-026539
Marq-6B	402-413	502-513	7326-8292(?)	000035-000038, 030001-030981(?)
Marq-7	414-429	514-529	7326-8749	031052-032476

There is no tape 430

Line	Tapes	Reels	Files	Shot Points
Marq-8	431	531	7326-7414	032588-032676
	432-451	534-553	7417-9132	032684-034403

There are no tapes 452 or 453

Line	Tapes	Reels	Files	Shot Points
Marq-9	454-459	554-559	7326-7859	034637-035174
	560-674	560-674	7860-8086	035175-045401
	(tape numbering system changed so that tape numbers will equal reel numbers)			

Line	Tapes	Reels	Files	Shot Points
Marq-10	675-844	675-844	7326-2383	045579-060634
Marq-10B	845-987	845-987	2384-5054	060685-073371
Tua-1	988-1020	988-1020	2384-5253	073392-076274
Tua-2	1021-1150	1021-1150	2384-3954	076325-088243
Soc-1	1151-1179	1151-1179	2384-4964	088307-090887
Soc-2	1180-1184	1180-1184	2384-2799	090947-091352

EW9103 Sonobuoy Logs

Ew9103 Sonobuoy Logs: Marquesas-Tuamoto-Society Islands													
SB	Line		Start Date			End Date							
#	#	Julian	Calendar	GMT	Julian	Calendar	GMT	Latitude	Longitude	Reel #	File #	SP #	Notes
1	Marq-1D	136	16-May	18:42	136	16-May	22:00+	S 08° 48.16'	W 141° 19.31'	162	3160	17081	
2	Marq-1E	138	18-May	2:48	138	18-May	06:00+	S 07° 14.225'	W 139° 23.58'	130	1192	1141	
3	Marq-2D	139	19-May	15:11	139	19-May	21:09+	S 07° 33.655'	W 137° 21.058'	297	7162	7822	
4	Marq-2F	139	19-May	23:35	140	20-May	03:08+	S 08° 2.993'	W 136° 58.88'	315	7660	9240	
5	Marq-3	141	21-May	20:10	141	21-May	23:55+	S 10° 30.476'	W 129° 09.749'	409	3834	17268	
6	Marq-4	142	22-May	20:15	142	22-May	23:30+	S 11° 07.340'	W 138° 56.851'	450	7446	21605	
7	Marq-4	143	23-May	4:55	143	23-May	8:23+	S 10° 55.852'	W 138° 16.368'	468	9006	unk	
8	Marq-5	143	23-May	10:31	143	23-May	13:00+	S 10° 58.069'	W 137° 54.408'	478	6086	24168	
9	Marq-6	143	23-May	19:22	143	23-May	23:05+	S 11° 13.722'	W 137° 25.320'	492	6331	25764	
10	Marq-6B	144	24-May	2:15	144	24-May	5:00+	S 11° 05.023'	W 136° 54.545'	507	7725	unk	
11	Marq-8	144	24-May	15:27	144	24-May	18:43+	S 11° 48.131'	W 136° 42.123'	533	7521	unk	
12	Marq-10	148	28-May	0:39	148	28-May	05:31+	S 07° 32.372'	W 137° 16.271'	695	9153	47406	
13	Marq-10	148	28-May	7:36	148	28-May	10:37	S 07° 56.213'	W 137° 44.656'	709	406	48658	lost 30 min. due to out
14	Marq-10	148	28-May	10:37	148	28-May	13:23	S 08° 06.18'	W 137° 55.26'	715	949	49201	of tune
15	Marq-10	148	28-May	13:25	148	28-May	16:12	S 08° 15.75'	W 138° 07.80'	721	1453	49705	
16	Marq-10	148	28-May	16:13	148	28-May	18:36+	S 08° 24.998'	W 139° 18.168'	727	1957	50209	
17	Marq-10	148	28-May	19:03	149	29-May	0:35	S 08° 34.269'	W 138° 30.093'	732	2466	50718	21:51-0:35 not recorded
18	Marq-10	148	28-May	21:51	149	29-May	01:56+	S 08° 43.69'	W 138° 40.287'	738	2976	51219	
19	Marq-10	149	29-May	0:35	149	29-May	3:21	S 08° 52.78'	W 138° 52.08'	744	3462	51714	0:35-1:56 not recorded
20	Marq-10	149	29-May	3:21	149	29-May	6:08	S 09° 02.110'	W 139° 02.750	749	3962	52214	
21	Marq-10	149	29-May	6:08	149	29-May	6:35	S 09° 11.626'	W 139° 14.581'	755	4461	52713	died after 10 min. in water
22	Marq-10	149	29-May	6:35	149	29-May	9:15	S 09° 13.188'	W 139° 16.280'	756	4542	52794	recorded to 9:07
23	Marq-10	149	29-May	9:07	149	29-May	11:47	S 09° 21.723'	W 139° 26.347'	761	4999	53251	
24	Marq-10	149	29-May	11:47	149	29-May	14:30+	S 09° 30.243'	W 139° 36.543'	766	5479	53731	
25	Marq-10	149	29-May	14:34	149	29-May	17:00+	S 09° 39.49'	W 139° 47.571'	772	5981	54233	
26	Marq-10B	153	2-Jun	4:33	153	2-Jun	07:30+	S 15° 56.104'	W 145° 45.015'	946	1407	69708	
27	Tua-1	154	3-Jun	3:43	154	3-Jun	06:14+	S 14° 43.408'	W 147° 38.734'	993	2868	73876	
28	Tua-1	154	3-Jun	7:45	154	3-Jun	11:00+	S 14° 43.324'	W 148° 02.276'	1001	3600	74609	
29	Tua-2	155	4-Jun	16:41	155	4-Jun	19:22	S 16° 40.029'	W 149° 50.477'	1071	6855	81136	
30	Tua-2	156	5-Jun	5:40	156	5-Jun	9:42+	S 17° 42'	W 150° 20'	1098	9330	83617	
31	Soc-1	157	6-Jun	20:23	157	6-Jun	20:52	S 20° 06.354'	W 150° 15.397'	1176	4661	90584	sonobuoy died

EW9103 Line Surveys

	EW9103 Line Surveys: Marquesas-Tuamoto-Society Islands								
	Line Number	Day/Date	Time	Latitude	Longitude	Reel #	File #	Shotpoint #	Notes
Start	Marq-1	135/15 May 91	1558:00	S 10° 12.115'	W 143° 03.823'	105	100	12271	
End		135/15 May 91	1740:00	S 10° 07.527'	W 142° 57.688'	108	391	12563?	
	Marq-1A	135/15 May 91	1741:28	S 10° 07.441'	W 142° 57.570'	109	100*	12579	
		135/15 May 91	2156:00	S 09° 51.918'	W 142° 38.802'	117	844?	13343?	
	Marq-1B	135/15 May 91	2156:00	S 09° 51.918'	W 142° 38.807'	118	100*	0-13590*	
		135/15 May 91	2248:00	S 09° 50.130'	W 142° 36.707'	119	264	13843-0*	
	Marq-1C	135/15 May 91	2248:00	S 09° 50.130'	W 142° 36.707'	120	100*	0-13590*	
		136/16 May 91	0130:00	S 09° 42.942'	W 142° 26.142'	125	552	13843-0*	
	Marq-1D	136/16 May 91	0130:00	S 09° 41.972'	W 142° 36.707'	126	100*	13990?	
		137 17 May 91	2008:00	S 07° 42.032	W 139° 40.915'	216	7686?	21643?	
	Marq-1E	137/17 May 91	2024:00	S 07° 40.840'	W 139° 40.453'	217	100*	33*	
		138/18 May 91	1953:00	S 06° 21.66'	W 138° 18.375'	266	4249	4256*	
	Marq-2	138/18 May 91	2039:02	S 06° 22.363'	W 138° 15.643'	267	4250	4396	
		139/19 May 91	0120:24	S 06° 40.700'	W 138° 01.670	276	5095	5241	
	Marq-2B	139/19 May 91	0357:43	S 06° 50.517'	W 137° 54.009'	273	5096	5712	there are two tapes
		139/19 May 91	0410:43	not logged	not logged	273	5135	5771	numbered 273-276
	Marq-2C	139/19 May 91	0417:43	S 06° 53.195'	W 137° 52.586'	274	5136	5772	
		139/19 May 91	0917:00	S 07° 10.436'	W 137° 39.040'	284	6024	6670	
	Marq-2D	139/19 May 91	0920:00	S 07° 10.500'	W 137° 38.989'	285	6025	6681	
		139/19 May 91	1754:20	S 07° 42.199'	W 137° 14.486'	301	7454	8109?	
	Marq-2E	139/19 May 91	1754:20	S 07° 42.199	W 137° 14.486'	302	6025*	8221	
		139/19 May 91	1949:00	S 07° 49.188'	W 137° 08.502	307	6359?	8555?	
	Marq-2F	139/19 May 91	1954:00	S 07° 49.525'	W 137° 08.844'	308	7000	8580	
		140/20 May 91	0559:20	S 08° 26.112'	W 136° 40.772'	328	8816	10396	
	Marq-3	140/20 May 91	0611:20	S 08° 27.053'	W 136° 40.547'	331	7000	10432	
		142/22 May 91	0724:00	S 11° 050.070'	W 139° 51.951'	432	5853	19291	
	Marq-4	142/22 May91	1124:56	S 11° 19.228'	W 139° 39.944'	433	5854	20013	
		143/23 May 91	0831:00	S 10° 50.390'	W 137° 59.004'	475	9654	23813	
	Marq-5	143/23 May 91	0912:00	S 10° 54'	W 137° 55'	476	5854*	23936	
		143/23 May 91	1338:00	S 11° 12.45'	W 137° 51.34'	484	6651	24733	
	Marq-6	143/23 May 91	1527:00	S 11° 15.023	W 137° 44.088	485	5854*	25060	
		143/23 May 91	2340:00	S 11° 07.5'	W 137° 05.4'	501	7325	26539	
	Marq-6B	143/23 May 91	2356:01	S 11° 07.40'	W 137° 05.20'	502	7326	35-38*	
		144/24 May 91	0524:00	not logged	not logged	513	8292?	3001-30981*	
	Marq-7	144/24 May 91	0548:01	S 11° 03.074'	W 136° 40.489'	514	7326	31052	
		144/24 May 91	1342:00	S 11° 46.12'	W 136° 34.60'	529	8749	32476	

*Record numbers out of sequence

EW9103 Line Surveys

	EW9103 Line Surveys: Marquesas-Tuamoto-Society Islands								
	Line Number	Day/Date	Time	Latitude	Longitude	Reel #	File #	Shotpoint #	Notes
Start	Marq-8	144/24 May 91	1419:00	S 11° 46.709'	W 136° 36.023'	531	7326-	32588-	
End							7414	32676	
						534-	7417-	32684-	
		145/25 May 91	0024:00	S 11° 53.75'	W 137° 30.35'	553	9132	34403	
	Marq-9	145/25 May 91	0142:40	S 11° 55.54'	W 137° 27.76'	554	7326*	34637	
		147/27 May 91	1330:40	S 06° 58.02'	W 136° 37.53'	674	8086	45401	
	Marq-10	147/27 May 91	1430:00	S 06° 59.42'	W 136° 37.29'	675	7326*	45579	
		151/31 May 91	0208:21	S 11° 36.056'	W 142° 06.901'	844	2383	60634	
	Marq-10B	151/31 May 91	1430:00	S 11° 35.09'	W 142° 06'	845	2384	60685	
		154/03 June 91	0058:22	S 14° 43.377'	W 147° 24.487'	987	5054	73371	
	Tua-1	154/03 June 91	0101:41	S 14° 43'	W 147° 25'	988	2384*	73392	
		154/03 June 91	1632:20	S 14° 44.01'	W 148° 53.55'	1020	5253	76274	
	Tua-2	154/03 June 91	1648:49	S 14° 44.83'	W 148° 54.72'	1021	2384*	76325	
		157/06 June 91	0724:00	S 19° 32.654'	W 151° 15.048'	1150	3954	88243	
	Soc-1	157/06 June 91	0744:41	S 19° 34.154'	W 151° 14.134'	1151	2384	88307	
		157/06 June 91	2204:40	S 20° 10.382	W 150° 07.377'	1179	4964	90887	
	Soc-2	157/06 June 91	2225:09	S 20° 09.881'	W 150° 05.815'	1180	2384*	90947	
		157/06 June 91	0043:01	S 19° 57.282'	W 150° 01.000'	1184	2799	91352	

*Record numbers out of sequence

SONOBUOY SUMMARY

Number: 1

Time: 16 May, 1991 JD 136 1842z to 2200z

Location: 8°48.16S, 141°19.31W to 8°38.41S, 141°07.70W

Line Number: Marq1.

Tectonic Setting: Deepest part of flexural moat on west side of Marquesas

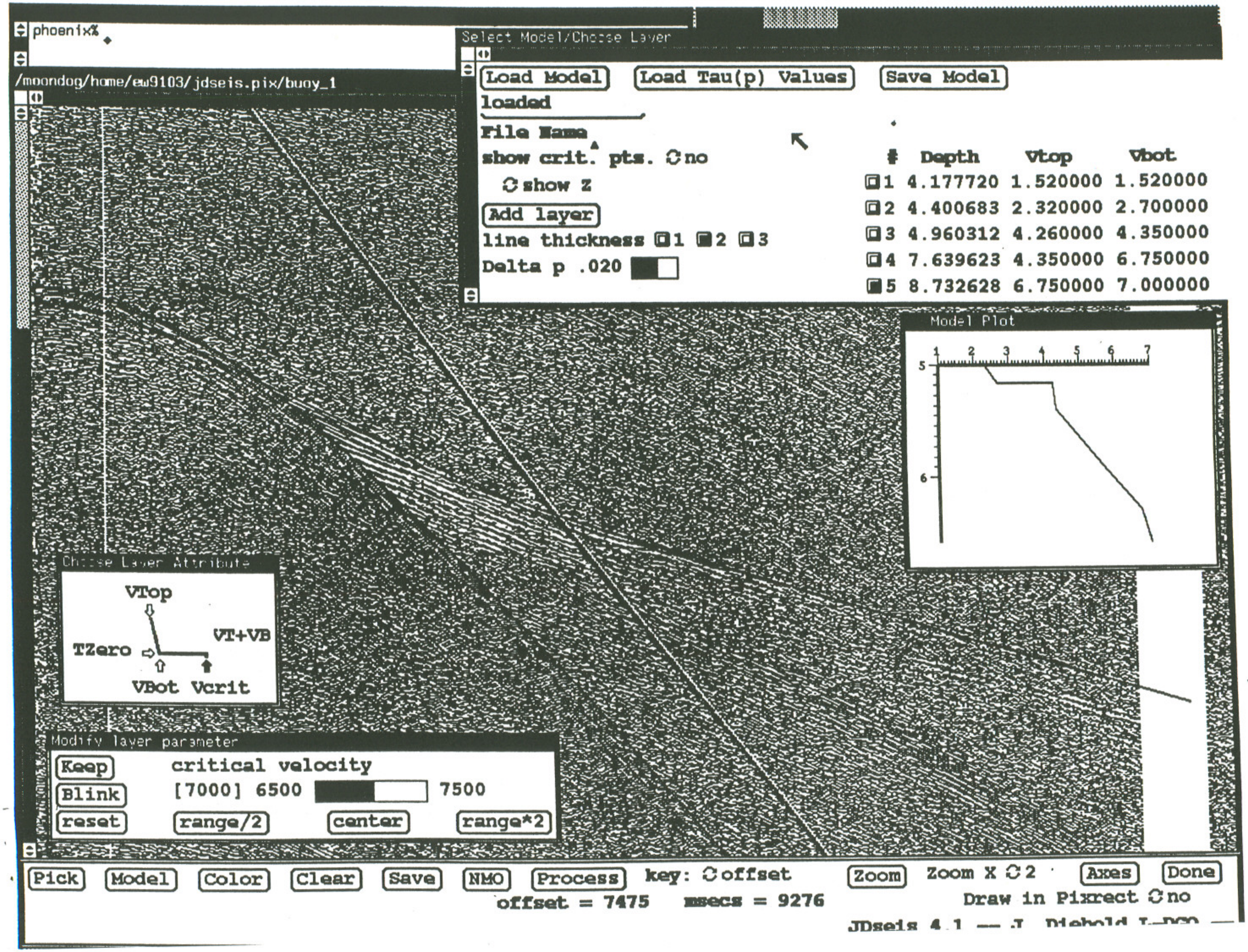
Depth: 4160 m to 3835 m

Course and Speed: 48°, 4.9 kts

MCS Tapes: 58 to 65

MCS Files: 3160, shot 17081

Summary of Results from Modeling with JDSeis:
5 layer model:
(1) Depth 4.1777 km, with upper and lower velocities of 1.52 km/s. Water.
(2) Depth 4.4007 km (thickness 223 m), with upper and lower velocities of 2.32 to 2.7 km/sec. Pelagic sediment.
(3) Depth 4.9603 km (thickness 560 m), with upper and lower velocities of 4.26 to 4.35 km/s. Volcanic sediments?
(4) Depth 7.6396 km (thickness 2.68 km), with upper and lower velocities of 4.35 to 6.75 km/s. Upper (preexisting) oceanic crust (layer 2), grading into lower crust?
(5) Depth 8.7326 km (thickness 1.09 km), with upper and lower velocities of 6.75 to 7.00 km. Part of layer 3 (lower oceanic crust)?



phoenix%
/moondog/home/ew9103/jdseis.pix/buoy_1
Select Model/Choose Layer
Load Model
Load Tau(p) Values
Save Model
loaded
File Name
show crit. pts. no
show Z
Add layer
line thickness 1 2 3
Delta p .020
Depth Vtop Vbot
1 4.177720 1.520000 1.520000
2 4.400683 2.320000 2.700000
3 4.960312 4.260000 4.350000
4 7.639623 4.350000 6.750000
5 8.732628 6.750000 7.000000
Model Plot
Choose Layer Attribute
VTop
TZero
VT+VB
VBot
Vcrit
Modify layer parameter
Keep
Blink
reset
critical velocity
[7000] 6500
7500
range/2
center
range*2
Pick
Model
Color
Clear
Save
NMO
Process
key: offset
offset = 7475
msecs = 9276
Zoom
Zoom X 2
Axes
Done
Draw in Pixrect no

Number: 4

Time: 19 May, 1991 JD 139 2335z to 20 May, 1991 JD 140 0308z

Location: 8°2.993S, 136°58.588W to 8°15.556S, 136°48.906W

Line Number: Marq2

Tectonic Setting: Normal lithosphere on far side of flexural arch east of the Marquesas.

Depth: 4360 to 4403.5

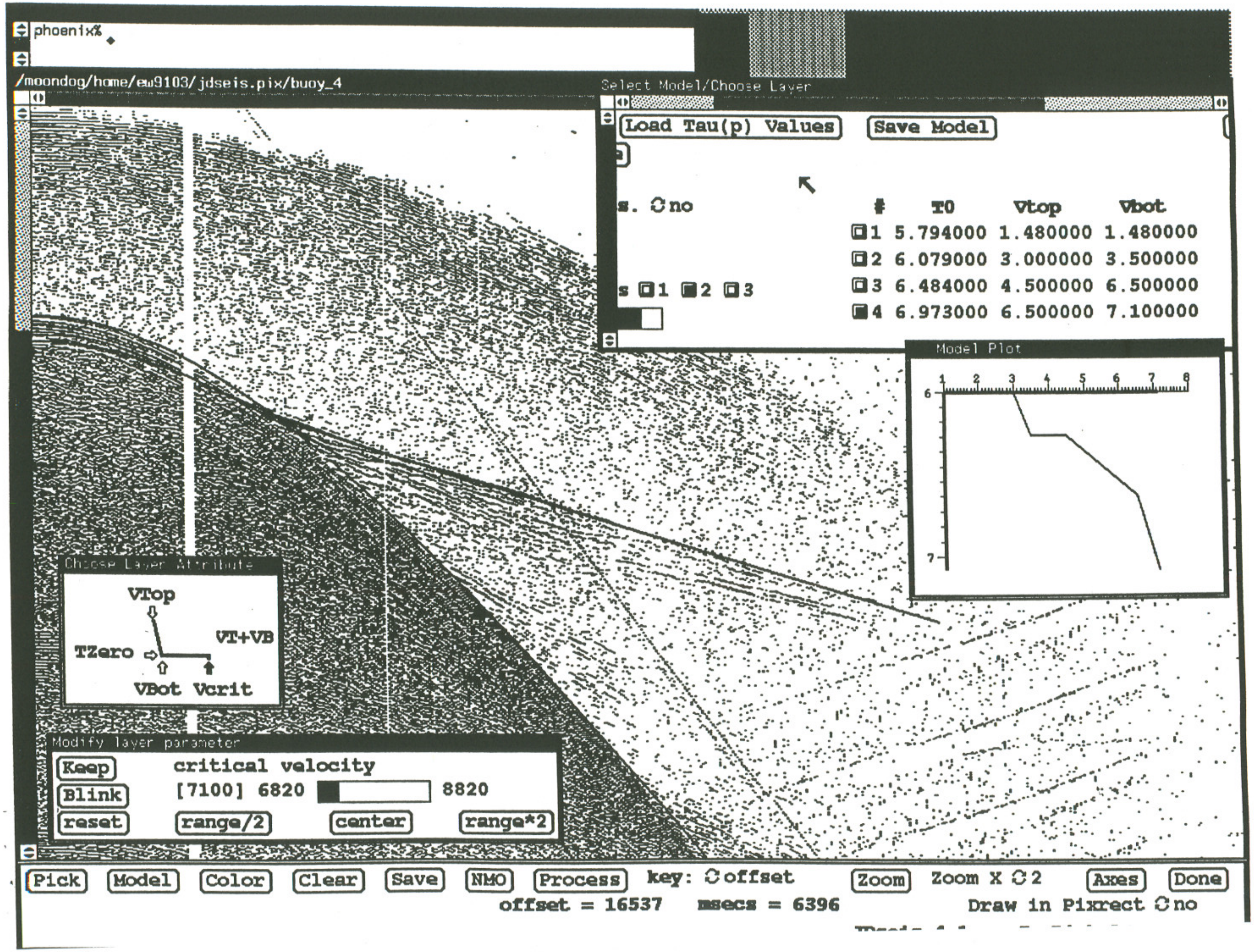
Côurse and Speed: 134°, 4.8 kts

MCS Tapes: 215-222

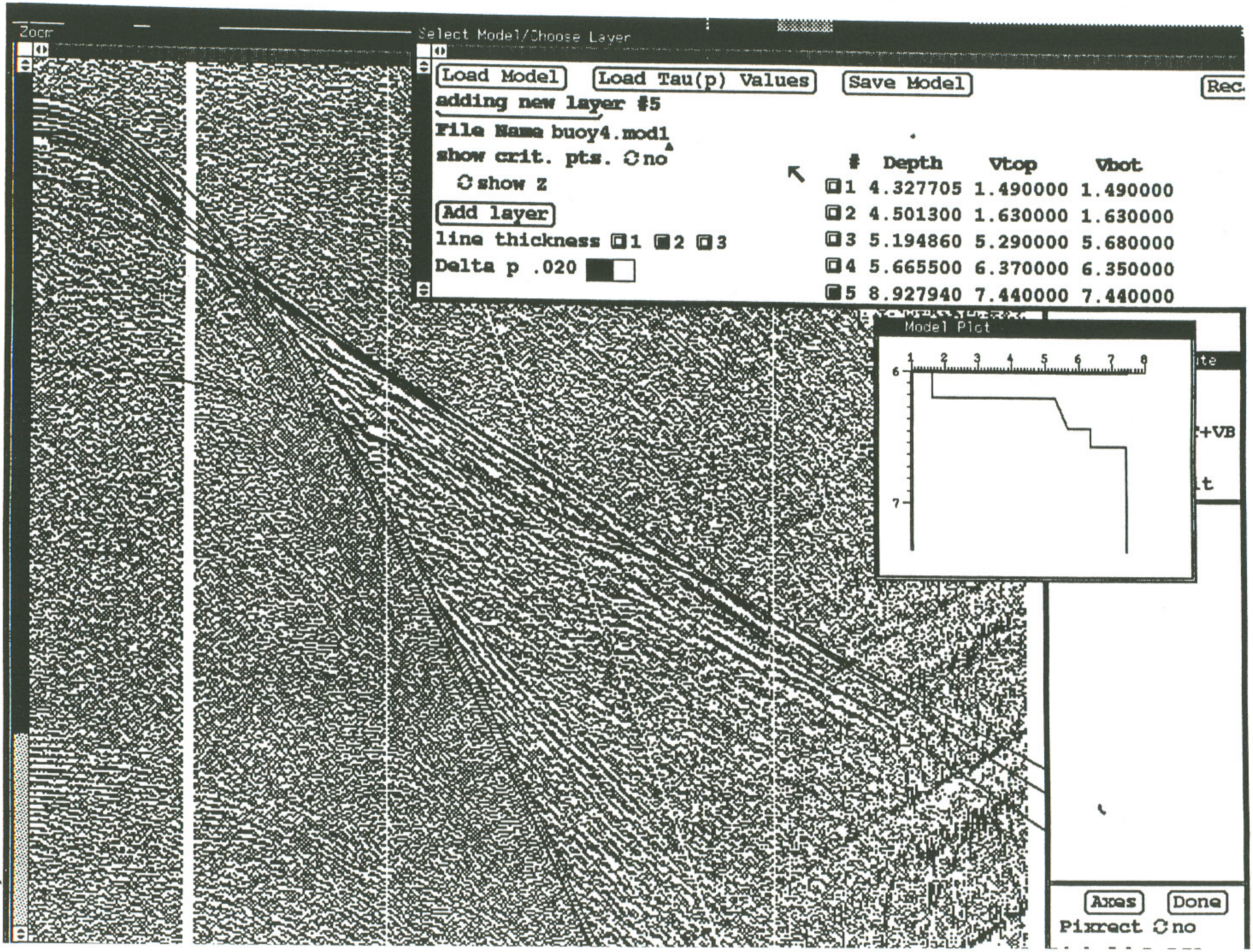
MCS Files: 7660 - 8303, shot points 9240 - 9883

Summary of Results from Modeling with JDSeis:
Caress: 4 layer model:
(1) Depth 5.794 km with uniform velocity of 1.48 km/s. Water.
(2) Depth 6.079 km (thickness 285 m) with upper and lower velocities of 3.00 to 3.5 km/s. Pelagic sediments?
(3) Depth 6.484 km (thickness 405 m) with upper and lower velocities of 4.5 to 6.5 km/s. Oceanic layer 2.
(4) Depth 6.973 km (thickness 489 m) with upper and lower velocities of 6.5 to 7.1 km/s. Upper part of oceanic layer 3.

Ito: 5 layer model:
(1) Depth 4.327 km with uniform velocity of 1.49 km/s. Water.
(2) Depth 4.501 km (layer thickness 174 m) with upper and lower velocities of 1.63 km/s. Pelagic sediments.
(3) Depth 5.195 km (layer thickness 694 m) with upper and lower velocities of 5.29 to 5.68 km/s. Upper oceanic crust.
(4) Depth 5.666 km (layer thickness 472 m) with upper and lower velocities of 6.37 to 6.35 km/s.
(5) Depth 8.928 km (layer thickness 3.262 km) with upper and lower velocities of 7.44 km/s.



phoenix%
/moondog/home/ew9103/jdseis.pix/buoy_4
Select Model/Choose Layer
Load Tau(p) Values
Save Model
s. no
T0 Vtop Vbot
1 5.794000 1.480000 1.480000
2 6.079000 3.000000 3.500000
3 6.484000 4.500000 6.500000
4 6.973000 6.500000 7.100000
s 1 2 3
Model Plot
Choose Layer Attribute
VTop
TZero
VT+VB
VBot Vcrit
Modify layer parameter
Keep
Blink
reset
critical velocity
[7100] 6820
8820
range/2
center
range*2
Pick
Model
Color
Clear
Save
NMO
Process
key: offset
Zoom
Zoom X 2
Axes
Done
offset = 16537
msecs = 6396
Draw in Pixrect no


Zoom
Select Model/Choose Layer
Load Model
Load Tau(p) Values
Save Model
Rec.
adding new layer #5
File Name buoy4.mod1
show crit. pts. no
show Z
Add layer
line thickness 1 2 3
Delta p .020
Depth Vtop Vbot
1 4.327705 1.490000 1.490000
2 4.501300 1.630000 1.630000
3 5.194860 5.290000 5.680000
4 5.665500 6.370000 6.350000
5 8.927940 7.440000 7.440000
Model Plot
1 2 3 4 5 6 7 8
6
7
+VB
Axes
Done
Pixrect no

Number: 9

Time: 23 May, 1991 JD 143 1922z to 2305z

Location: 11°13.722S, 137°25.300W to 11°9.13S, 137°08.81W

Line Number: Marq6

Tectonic Setting: Western end of Marquesas Fracture Zone Ridge

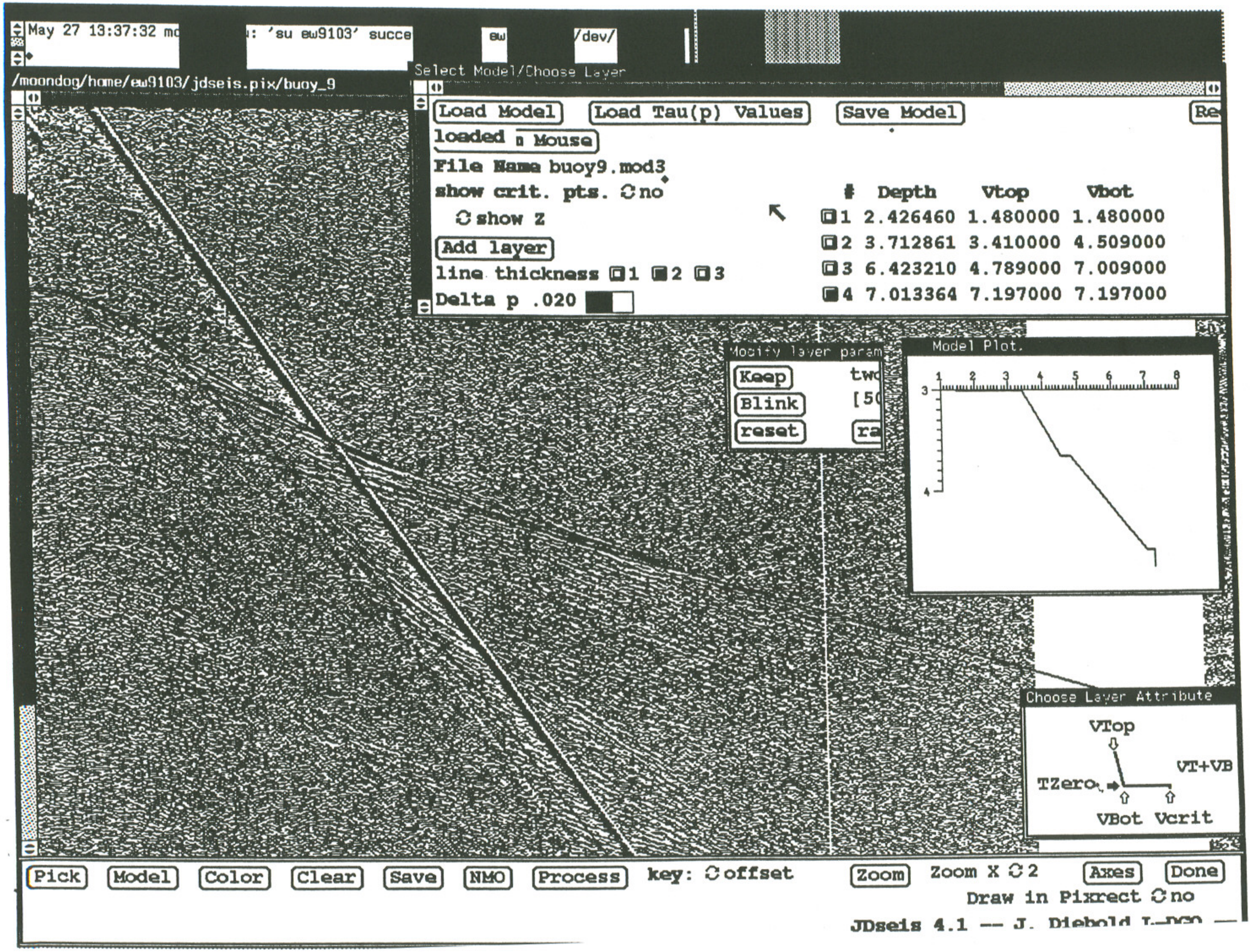
Depth: 2460 m to 2459 m

Course and Speed: 76°, 5.0 kts

MCS Tapes: 392 to 400

MCS Files: 6551 to 7219, shot points 25764 to 26433

Summary of Results from Modeling with JDSeis:
Four layer model:
(1) Depth 2.426 km, with upper and lower velocities of 1.48 km/s. Water.
(2) Depth 3.713 km (layer thickness 1287 m), with upper and lower velocities of 3.41 km/s to 4.50 km/s.
(3) Depth 6.423 km (layer thickness 2.71 km), with upper and lower velocities of 4.789 to 7.009 km/s.
(4) Depth 7.0133 km (layer thickness 590 m), with upper and lower velocities of 7.197 km/s.


May 27 13:37:32
'su ew9103' succe
/dev/
/moondog/home/ew9103/jdseis.pix/buoy_9
Select Model/Choose Layer
Load Model
Load Tau(p) Values
Save Model
loaded
Mouse
File Name buoy9.mod3
show crit. pts. no
show Z
Add layer
line thickness 1 2 3
Delta p .020
Depth Vtop Vbot
1 2.426460 1.480000 1.480000
2 3.712861 3.410000 4.509000
3 6.423210 4.789000 7.009000
4 7.013364 7.197000 7.197000
Keep
Blink
reset
Model Plot
Choose Layer Attribute
VTop
VT+VB
TZero
VBot Vcrit
Pick
Model
Color
Clear
Save
NMO
Process
key: offset
Zoom
Zoom X 2
Axes
Done
Draw in Pixrect no
JDseis 4.1 -- J. Diebold

Number: 11

Time: 24 May, 1991 JD 144 1527z to 1843z

Location: 11°48.131S, 136°42.123W to 11°49.903S, 136° 59.053W

Line Number: Marq8

Tectonic Setting: Abyssal hill fabric of the Superswell directly south of the MFZR

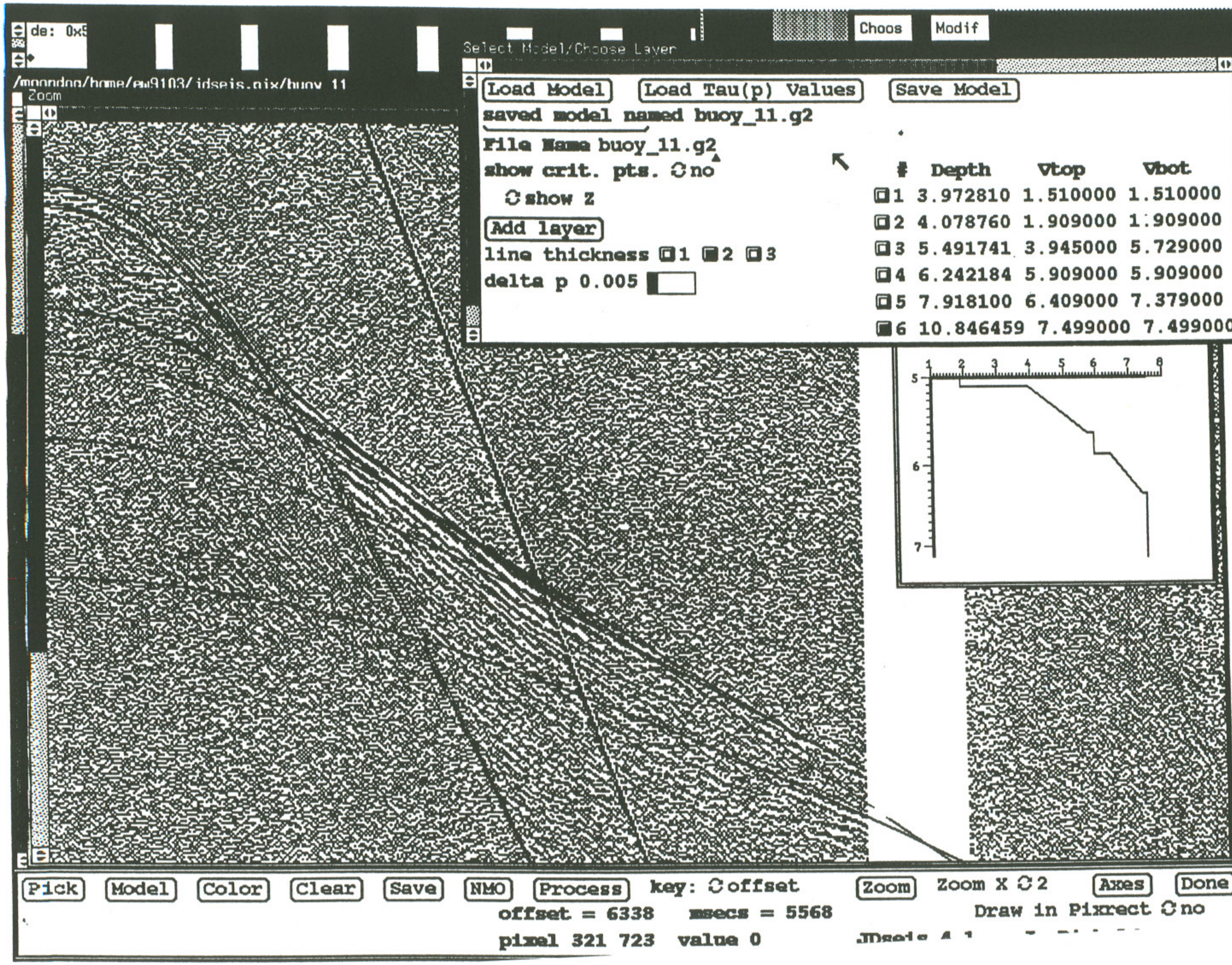
Depth: 3975 m to 4053 m

Course and Speed: 270°, 4.8 kts

MCS Tapes: 433 to 439

MCS Files: 7521 to 8100

Summary of Results from Modeling with JDSeis:
Six layer model:
(1) Depth 3.973 km, with upper and lower velocities of 1.51 km/s. Water.
(2) Depth 4.079 km (layer thickness 105 m), with upper and lower velocities of 1.909 km/s. Pelagic sediment.
(3) Depth 5.492 km (layer thickness 1.413 km), with upper and lower velocities of 3.945 to 5.729 km/s. Upper oceanic crust.
(4) Depth 6.242 km (layer thickness 750 m), with upper and lower velocities of 5.909 km/s.
(5) Depth 7.918 km (layer thickness 1.676 km) with upper and lower velocities of 6.409-7.379 km/s.
(6) Depth 10.846 km (layer thickness 2.928 km) with upper and lower velocities of 7.499 km/s.


Choos
Modif
Select Model/Choose Layer
/moondog/home/ew9103/idseis.nix/buoy_11
Zoom
Load Model
Load Tau(p) Values
Save Model
saved model named buoy_11.g2
File Name buoy_11.g2
show crit. pts. no
show z
Add layer
line thickness 1 2 3
delta p 0.005
Depth Vtop Vbot
1 3.972810 1.510000 1.510000
2 4.078760 1.909000 1.909000
3 5.491741 3.945000 5.729000
4 6.242184 5.909000 5.909000
5 7.918100 6.409000 7.379000
6 10.846459 7.499000 7.499000
Pick
Model
Color
Clear
Save
NMO
Process
key: offset
Zoom
Zoom X 2
Axes
Done
offset = 6338 msecs = 5568
Draw in Pixrect no
pixel 321 723 value 0

Number: 12

Time: 28 May, 1991 JD 148 0039z to 0531z

Location: 7°32.372S, 137°16.271W to 7°48.994S, 137° 36.191W

Line Number: Marq10

Tectonic Setting: Abyssal hill fabric east of Marquesas, at intersection with buoy 3

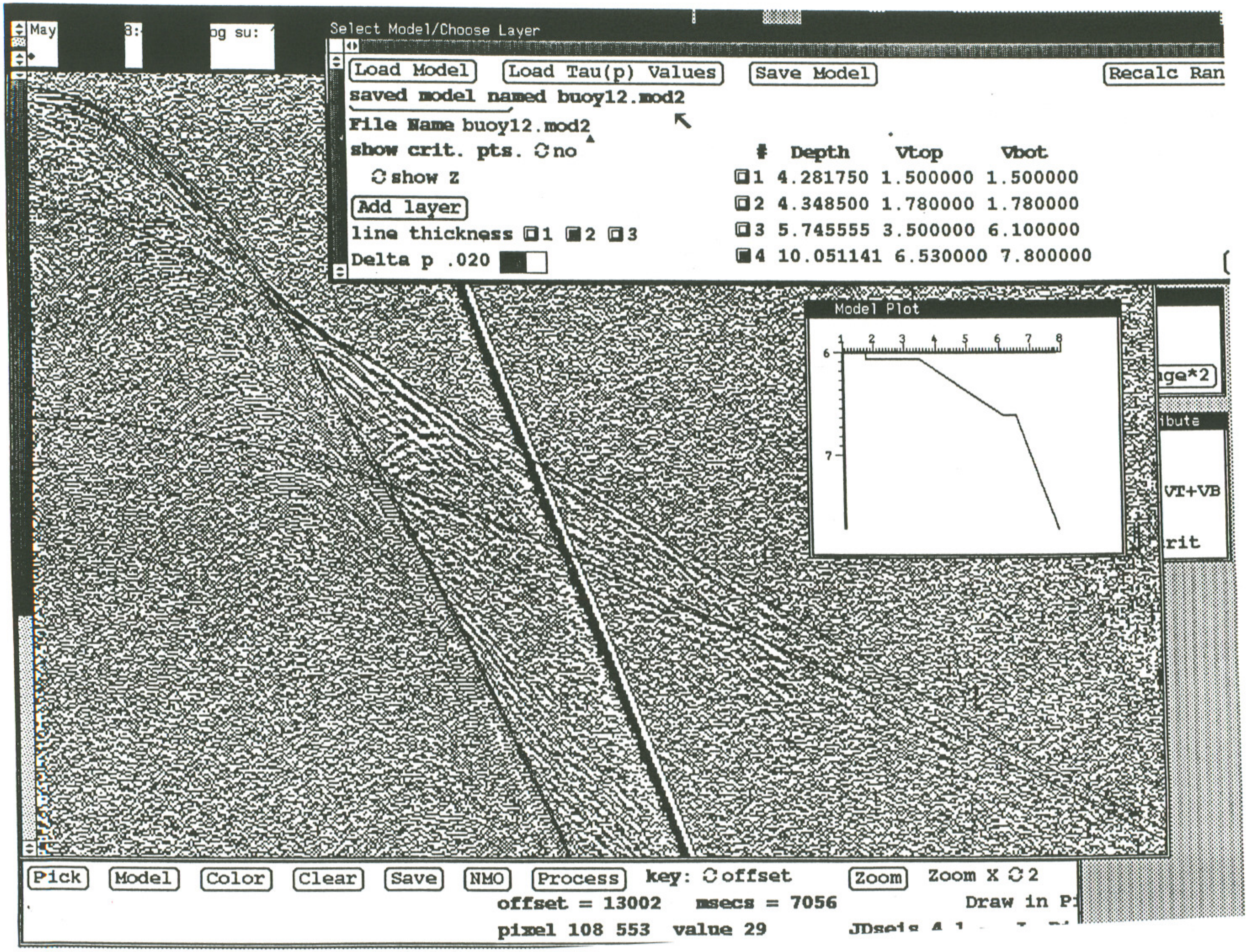
Depth: 4328 m to 4274 m

Course and Speed: 220°, 4.8 kts

MCS Tapes: 695 to 705

MCS Files: 9153 to 0030, shot points 47406-48282

Summary of Results from Modeling with JDSeis:
Four layer model:
(1) Depth 4.282 km, with upper and lower velocities of 1.50 km/s. Water.
(2) Depth 4.348 km (layer thickness 66 m), with upper and lower velocities of 1.78 km/s. Pelagic ooze.
(3) Depth 5.746 km (layer thickness 1.398 km), with upper and lower velocities of 3.5 to 6.1 km/s. Upper oceanic crust.
(4) Depth 10.051 km (layer thickness 4.305 km), with upper and lower velocities of 6.63 to 7.8 km/s. Rest of the oceanic crust.


May
Select Model/Choose Layer
Load Model
Load Tau(p) Values
Save Model
Recalc Ran
saved model named buoy12.mod2
File Name buoy12.mod2
show crit. pts. no
show Z
Add layer
line thickness 1 2 3
Delta p .020
Depth Vtop Vbot
1 4.281750 1.500000 1.500000
2 4.348500 1.780000 1.780000
3 5.745555 3.500000 6.100000
4 10.051141 6.530000 7.800000
Model Plot
1 2 3 4 5 6 7 8
6
7
ge*2
ibute
VT+VB
rit
Pick
Model
Color
Clear
Save
NMO
Process
key: offset
Zoom
Zoom X 2
offset = 13002 msecs = 7056
Draw in P
pixel 108 553 value 29

Number: 14

Time: 28 May, 1991 JD 148 1037:20z to 1323:01z

Location: 8°06.18S, 137°55.26W to 8°15.67S, 138° 07.69W

Line Number: Marq10

Tectonic Setting: Flexural moat and apron along central profile east of islands.

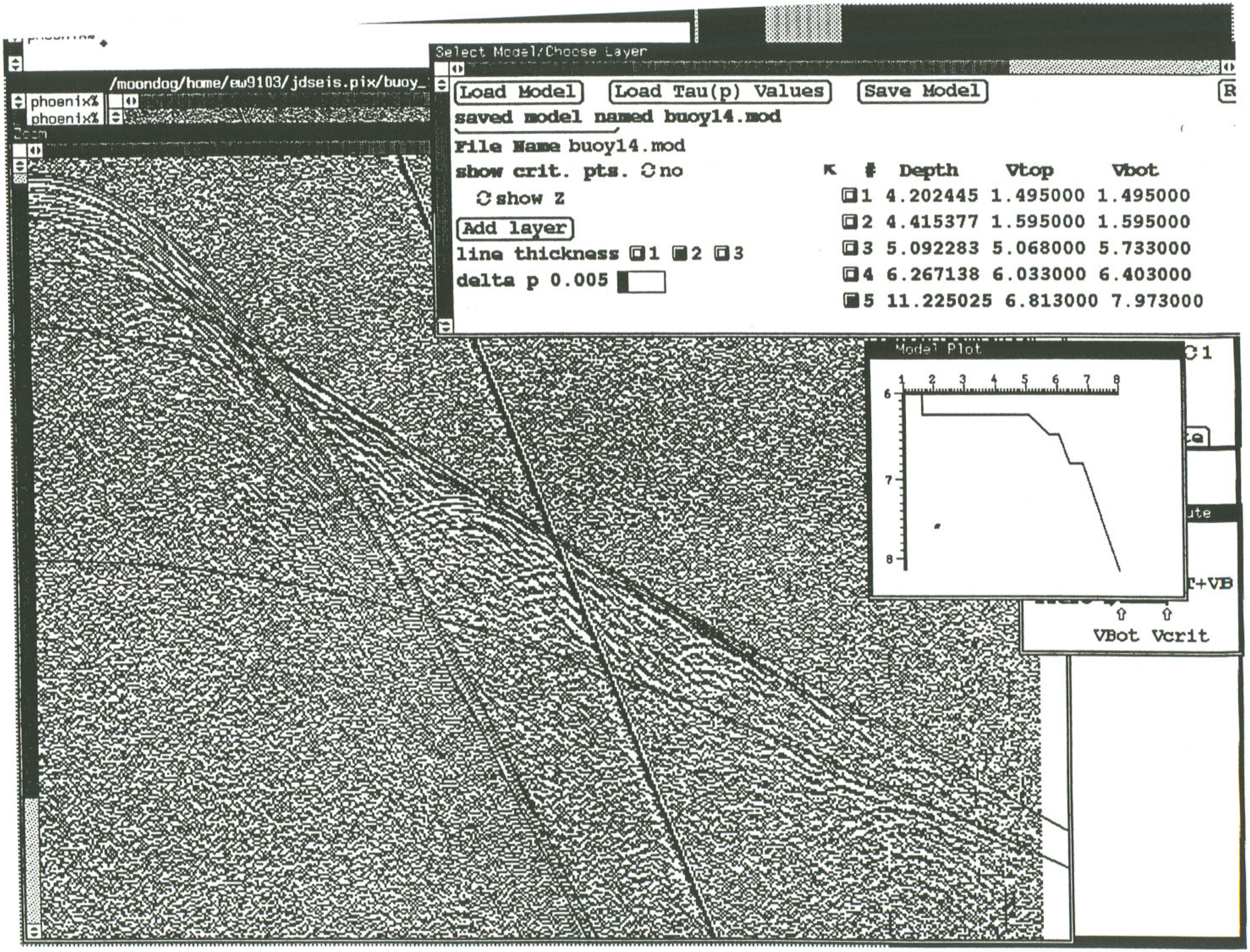
Depth: 4233 m to 4169 m

Course and Speed: 226°, 4.8 kts

MCS Tapes: 715 to 721

MCS Files: 949 to 1446, shot points 49201-49698

Summary of Results from Modeling with JDSeis:
Five layer model:
(1) Depth 4.202 km, with upper and lower velocities of 1.495 km/s. Water.
(2) Depth 4.4154 km (layer thickness 213 m), with upper and lower velocities of 1.595 km/s. Pelagic ooze.
(3) Depth 5.092 km (layer thickness 677 m), with upper and lower velocities of 5.068 to 5.733 km/s. Upper oceanic crust.
(4) Depth 6.267 km (layer thickness 1.175 km), with upper and lower velocities of 6.033 to 6.403 km/s. Oceanic crust.
(5) Depth 11.225 km (layer thickness 4.958 km), with upper and lower velocities of 6.813 to 7.973 km/s. Rest of the oceanic crust.



/moondog/home/ew9103/jdseis.pix/buoy_
phoenix%
phoenix%
Zoom
Select Model/Choose Layer
Load Model
Load Tau(p) Values
Save Model
saved model named buoy14.mod
File Name buoy14.mod
show crit. pts. no
show Z
Add layer
line thickness 1 2 3
delta p 0.005
Depth Vtop Vbot
1 4.202445 1.495000 1.495000
2 4.415377 1.595000 1.595000
3 5.092283 5.068000 5.733000
4 6.267138 6.033000 6.403000
5 11.225025 6.813000 7.973000
Model Plot
1 2 3 4 5 6 7 8
6
7
8
VBot Vcrit

APPENDIX 2
GRAVITY INTERPRETATION FOR THE MARQUESAS ISLANDS

Introduction

Gravity and bathymetry data collected on EW9103 were analysed in order to estimate the rigidity of the lithosphere supporting the island chain. The results from this analysis would be useful in interpreting the seismic reflection data and in determining the thermo-mechanical properties of the Pacific lithosphere in this area. One previous study had proposed that the elastic plate thickness in the Marquesas is only 14 km, and that therefore the area is part of the South Pacific Superswell. Another preliminary study has suggested that the stiffness of the plate increases from south to north along the chain, a trend that is inconsistent will all models of thermal evolution of lithosphere subjected to hot spot volcanism.

Our three profiles through the island chain were run at 050°, perpendicular to the overall trend of the chain (Figure 1). The southernmost profile between Hiva Oa and Fatu Iva samples the chain approximately 2 my after passage of the hot spot. The central line between Hiva Oa and Nuka Hiva samples the flexure approximately 3 to 4 my after passage of the hot spot, while the northernmost profile lies of lithosphere 4.5 my up the chain. Therefore, the data should constrain the thermo-mechanical evolution of the lithosphere for the first 5 my after volcanism.

The Data

The gravity data was collected with a KSS-30 gravimeter, and was reduced using the standard processing sequence that removed the International Gravity Formula and applied an Eötvös correction. Navigation was derived from GPS, which was generally available for 20 to 24 hours per day for the entire cruise. Because a drift correction could not be applied until after we reached port again, a trend was subtracted from each gravity profile. Removal of the trend should account for any gravimeter drift, plus any longer-wavelength regional signature unrelated to the flexure of the lithosphere beneath the islands. Bathymetry observations consisted of Hydro sweep center beam depths, when Hydrosweep was operating, or depth values digitized from the 3.5 kHz echo sounder when Hydrosweep was shut down for testing.

Bathymetry data from this expedition alone were not sufficient for modeling the gravity data; it had to be merged with other information in order to adequately model the gravity effect of off-track variations in depth. We first experimented with using dbdb5 bathymetry to model the gravity observations (Figure 2). Depths extracted from the dbdb5 5' grid along our track line disagreed with those measured by the ship by as much as 2 km (Figures 3, 4, 5). A visual inspection of the location of our track lines superimposed on the dbdb5 map (Figure 2) showed that the entire bathymetric map was mislocated to the southeast compared with our GPS navigated lines. Shifting the map to the northwest by 10' to 30', depending on the track line, improved the fit of the dbdb5 bathymetry to that of the ship, but inconsistencies made it impossible to extract any plate parameters using this bathymetric data base.

Next we tried using a 5 x 5 km grid of Marquesas bathymetry compiled by Karen Cianciulli at MIT and digitized by Paul Filmer. The sources of the data were Seabeam bathymetry from our previous expedition to the Marquesas in 1987, a French Gebco chart, some French sounding sheets. and dbdb5. This map more accurately reflected the bathymetry of the Marquesas, although it also had to be shifted to the northwest, but only by 5 km. This map was updated using the bathymetric data collected on this expedition in the following manner. Immediately beneath the ship track, depth values were changed to agree exactly with that measured. Off-track, for grid points closer than the distance l_{ramp} to a data point from our ship tracks, the depths were smoothly ramped to merge into those of the original map via the equation:

$$h_{newgrid} = \frac{d_{min}}{l_{ramp}} h_{grid} + \frac{l_{ramp} - d_{min}}{l_{ramp}} h_{data}$$

in which $h_{newgrid}$ is the new value assigned to the grid point. d_{min} is the distance to the nearest data point, h_{data} is the value of the depth at that data point, and h_{grid} is the original depth value at the grid point. The length l_{ramp} was dependent on the orientation of the line. For lines that ran perpendicular to the strike of the bathymetric features, such as those through the island chain, the ramp was 25 km long. For lines parallel to the strike, such as that along the Marquesas Fracture Zone Ridge, the ramp was only 10 km long. The new bathymetric map produced in this manner (Figure 1) produced an excellent fit to the gravity observations and was relatively free of any obvious artifacts from the admittedly crude smoothing scheme.

The profiles are named according to their MCS line designation. Marq 1 passes normal to the chain at the northwest end between the islands of Eiao and Nuka Hiva. Marq 10 passes through the central part of the chain between Nuka Hiva and Hiva Oa. Marq3 crosses the chain at the southeast end between the islands of Hiva Oa and Fam Iva. The Model

Using the bathymetric map derived above, we calculated theoretical free air gravity anomaly maps for the Marquesas area assuming that the bathymetry is a uniform-density load on a homogeneous thin elastic plate. The deflection of the plate was calculated using the linear filter derived from a 2-dimensional Fourier transformation of the thin plate equation. The calculation of gravity was performed in the Fourier domain, using the method of *Parker* [1972] to calculate the gravity effect of the water-rock interface (the observed bathymetry) and the Moho, assumed to be warped as the elastic plate. The higher order terms in the gravity were retained up to n=5 for the bathymetry, but only the linear term was necessary for the Moho deflection. The non-linear terms in the gravity from the bathymetry contributed up to 80 mgals to the highs over the islands, and up to 20 mgals between the islands where our gravity profiles crossed the chain, but made a negligible contribution to the gravity from the moat and arch.

From the calculated grid of free-air gravity from the elastic plate model, we extracted profiles coincident with the ship track. The linear trend best fitting the model gravity was subtracted before comparing the model to the detrended observations. Acceptable models were selected based on a visual comparison of the model and observed gravity, with emphasis being placed on correctly fitting the shape of the moat and arch. Less emphasis was placed on the amplitude of the gravity field over the volcanoes where errors in the bathymetry out of the plane of the profile might lead to some misfit.

Results

Assuming a density of 2650 kg/m^3 for the topography and an average depth to the Moho of 12 km (crustal thickness of 7 km), all three profiles through the Marquesas Islands are best fit by an elastic plate 17 km thick (Figures 6, 7, and 8). Assuming that the elastic plate thickness T_e is as stiff as 20 km (Figures 9, 10, and 11) or as weak as 14 km (Figures 12, 13, and 14) produces noticeably worse fits to the wavelength of the moats and arches and poorer fits to the amplitude of the gravity over the center of the chain.

If we decrease the density of the topography to 2500 kg/m^3, equally good fits to the data are obtained for an elastic plate thickness of 20 km (Figures 15, 16, and 17). If we increase the density of the topography to 2800 kg/m^3, the best-fitting elastic plate thickness drops to 15 km (Figures 18, 19, and 20). However, the fit to the data is not as good as with p_o=2650 kg/m^3 and T_e=17 km or with P_o=2500 kg/m^{3}and T_e=20 km.

The choice of 2650 kg/m^3 for the preferred topographic density was based on *Filmer's* [1991] three-dimensional analysis of the gravity field over a small seamount within the Marquesas for which we had complete Seabeam coverage. The seamount was short enough in wavelength such that its gravity field would not be influenced by isostatic compensation. Therefore, topographic density was the only free parameter in the model. If some compensation actually occurs at the wavelengths of analysis, or if the larger Marquesan volcanoes are under greater lithostatic pressure, then this value may actually underestimate the density of the Marquesas load. It is, however, unlikely that the average density could be less than 2650 km/m^3.

Therefore, we conclude that the best-fitting value of T_e for the Marquesas lithosphere is 17 km assuming a topographic density of 2650 kg/m^3. If the true density of the topography is either higher or lower than this value, then T_e values of 15 to 20 km are also allowed. However, based on the poorer fit to the gravity data, we consider the higher density unlikely, and based on modeling the gravity over a well-surveyed seamount, we consider the lower density also to be less likely.

Using the preferred plate parameters, we calculated the deflection of the Marquesas lithopshere beneath the chain. We predict that the pre-existing surface of the plate should lie at 10 km below sea level, which corresponds to a 5-km deflection of the plate beneath the chain. Our estimates of the maximum curvature of the plate beneath the island chain along our three profiles are 1.6 x 10^{-6}, 2.2 x 10^{-6}, and 3.6 x 10^{-6} m^{-1} for the southern, central, and northern profiles, respectively.

Implications

The elastic plate thickness for the Marquesas lithosphere is approximately 17 km, with no variation resolved along strike. This value is higher than the 14 km determined by *Calmant and Cazenave* [1987] from modeling altimetric data over the chain. Some of the discrepancy might result from their use of the dbdb5 data base. Because the volume of the island chain is overestimated in that data set, the stiffness of the lithosphere must be reduced in order to produce the same amplitude geoid signal over the islands.

The value we obtain for T_e is larger than that found anywhere on the Superswell, even on much older lithosphere. Thus we conclude that the Marquesas Islands lie north of the Superswell. The lack of variation along strike suggests that changes in elastic plate thickness as a result of viscoelastic relaxation or thermal rejuvenation are not important on the 2 to 5 m.y. time scale encompassed by our observations.

The fact that the gravity data are so well fit by the simple elastic plate model further suggests that the deep structure of the islands is fairly simple. We may not see anomalous crustal thickening beneath the island chain, such as that proposed for Oahu based on gravity and MCS data.

FIGURE CAPTIONS

Figure 1. Track lines for EW9103 in the Marquesas Islands superimposed on a new bathymetric map for the region derived from data from this expedition, *Crossgrain* 2 in 1987, and older French charts.

Figure 2. Same as Figure 1, except that the base map is dbdb5 digital bathymetry. A comparison with Figure 1 shows the mislocation of the islands relative to the track lines in this data set.

Figure 3. Comparison of dbdb5 bathymetry (dashed line) with that measured by the ship (solid line) for the southernmost line through the chain.

Figure 4. Comparison of dbdb5 bathymetry (dashed line) with that measured by the ship (solid line) for the central line through the chain.

Figure 5. Comparison of dbdb5 bathymetry (dashed line) with that measured by the ship (solid line) for the northernmost line through the chain.

Figure 6. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e=17 km and density of topography P_o=2650 kg/m^3 along the southernmost line through the island chain.

Figure 7. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e=17 km and density of topography P_o=2650 kg/m^3 along the central line through the island chain.

Figure 8. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e=17 km and density of topography P_o=2650 kg/m^3 along the northernmost line through the island chain.

Figure 9. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e=20 km and density of topography P_o=2650 kg/m^{3}along the southernmost line through the island chain.

Figure 10. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e =20 km and density of topography P_o =2650 kg/m^3 along the central line through the island chain.

Figure 11. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e =20 km and density of topography P_o =2650 kg/m^3 along the northernmost line through the island chain.

Figure 12. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e *=14* km and density of topography P_o *=2650* kg/m^3 along the southernmost line through the island chain.

Figure 13. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e *=14* km and density of topography P_o *=2650* kg/m^3 along the central line through the island chain.

Figure 14. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e *=14* km and density of topography *Po=2650* kg/m^3 along the northernmost line through the island chain.

Figure 15. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e *=20* km and density of topography P_o *=2500* kg/m^3 along the southernmost line through the island chain.

Figure 16. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e *=20* km and density of topography P_o *=2500* kg/m^3 along the central line through the island chain.

Figure 17. Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e *=20* km and density of topography P_o *=2500* kg/m^3 along the northernmost line through the island chain.

<u>Figure 18.</u> Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e =15 km and density of topography P_o *=2800* kg/m^3 along the southernmost line through the island chain.

<u>Figure 19.</u> Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with. elastic plate thickness T_e =15 km and density of topography P_o *=2800* kg/m^3 along the central line through the island chain.

<u>Figure 20.</u> Comparison of observed gravity (solid line) to theoretical gravity for an elastic plate model with elastic plate thickness T_e =15 km and density of topography P_o *=2800* kg/m^3 along the northernmost line through the island chain.

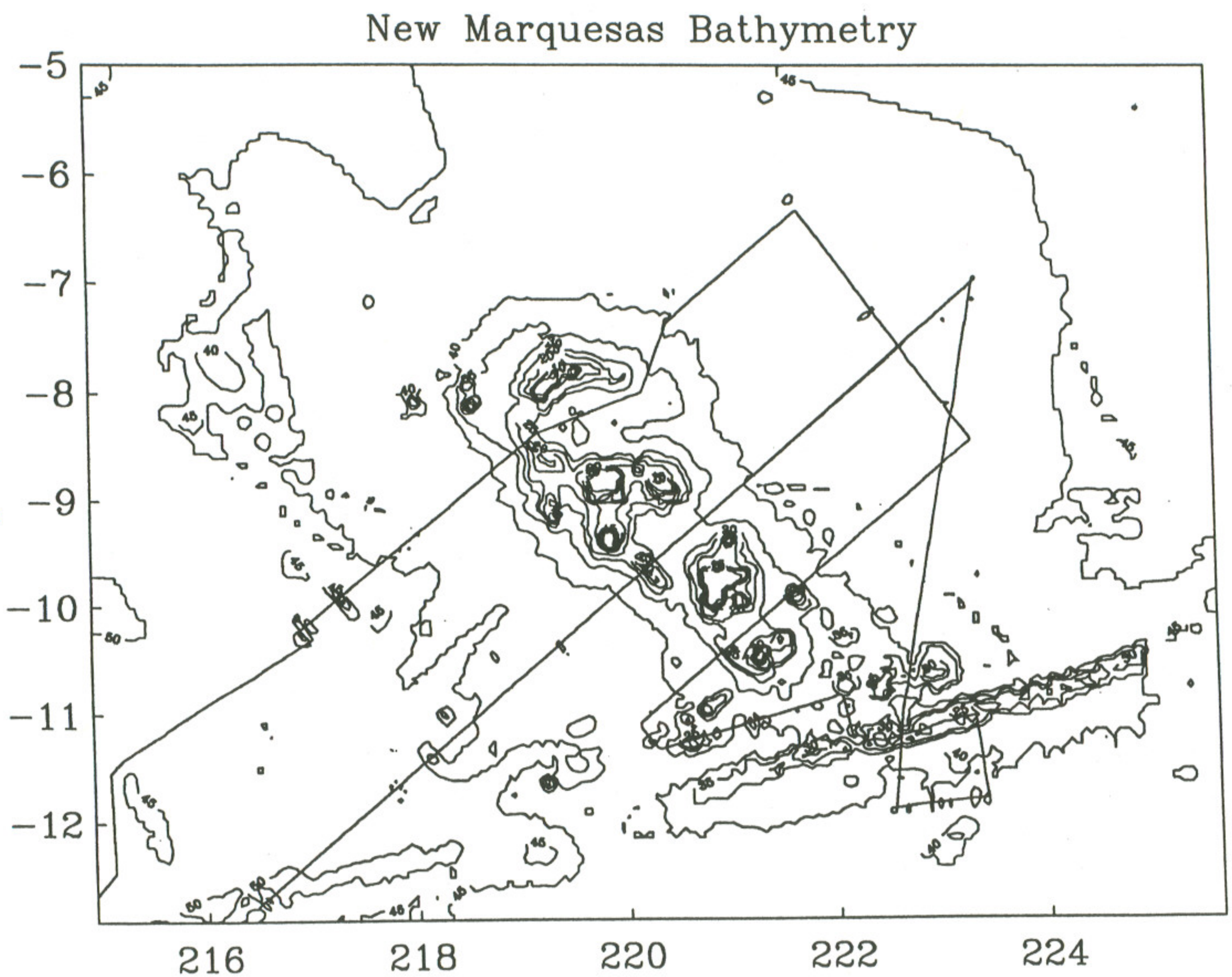
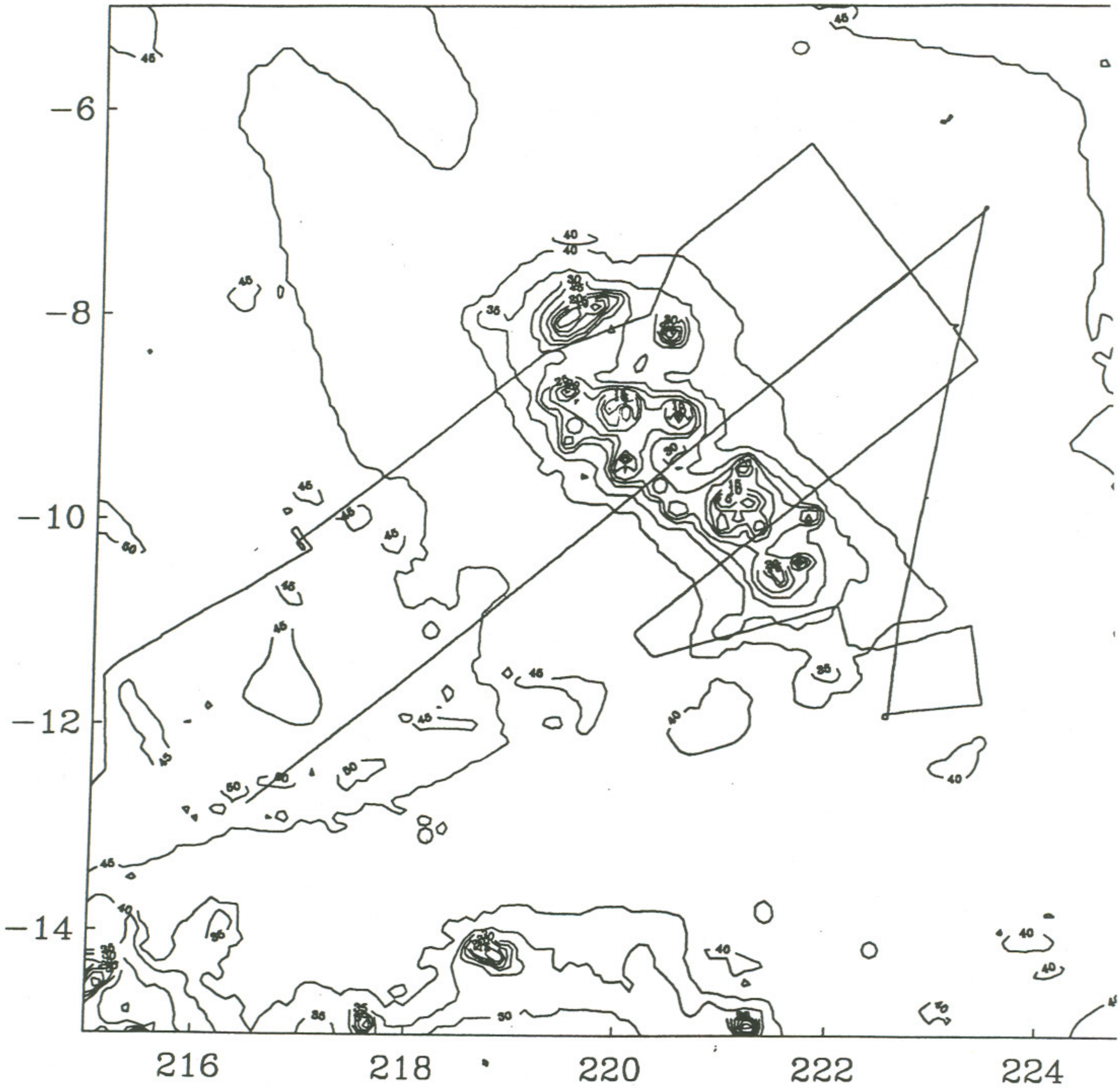


Fig 1



dbdb5

Fig 2

comparison of ship data to dbdb5

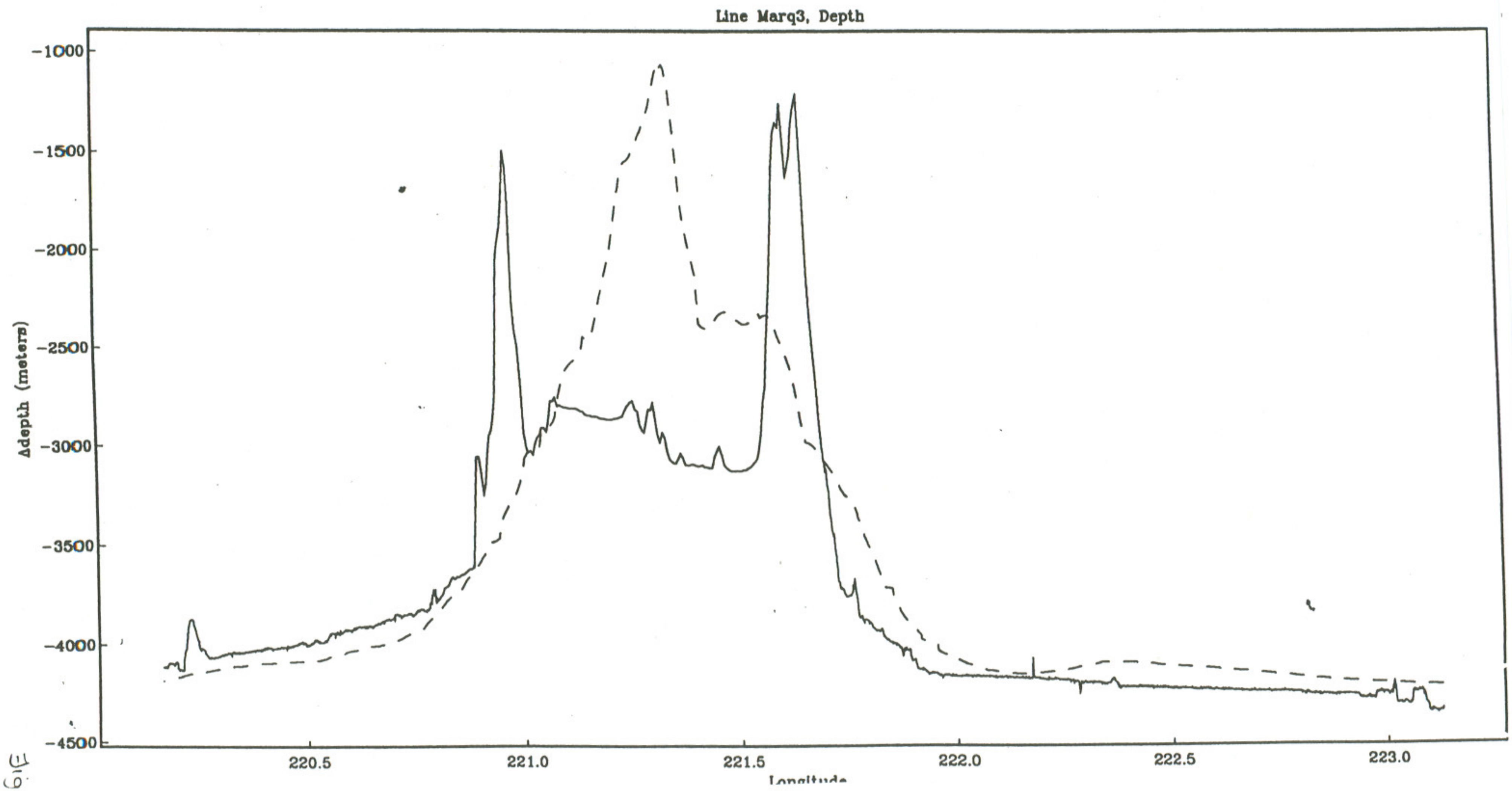
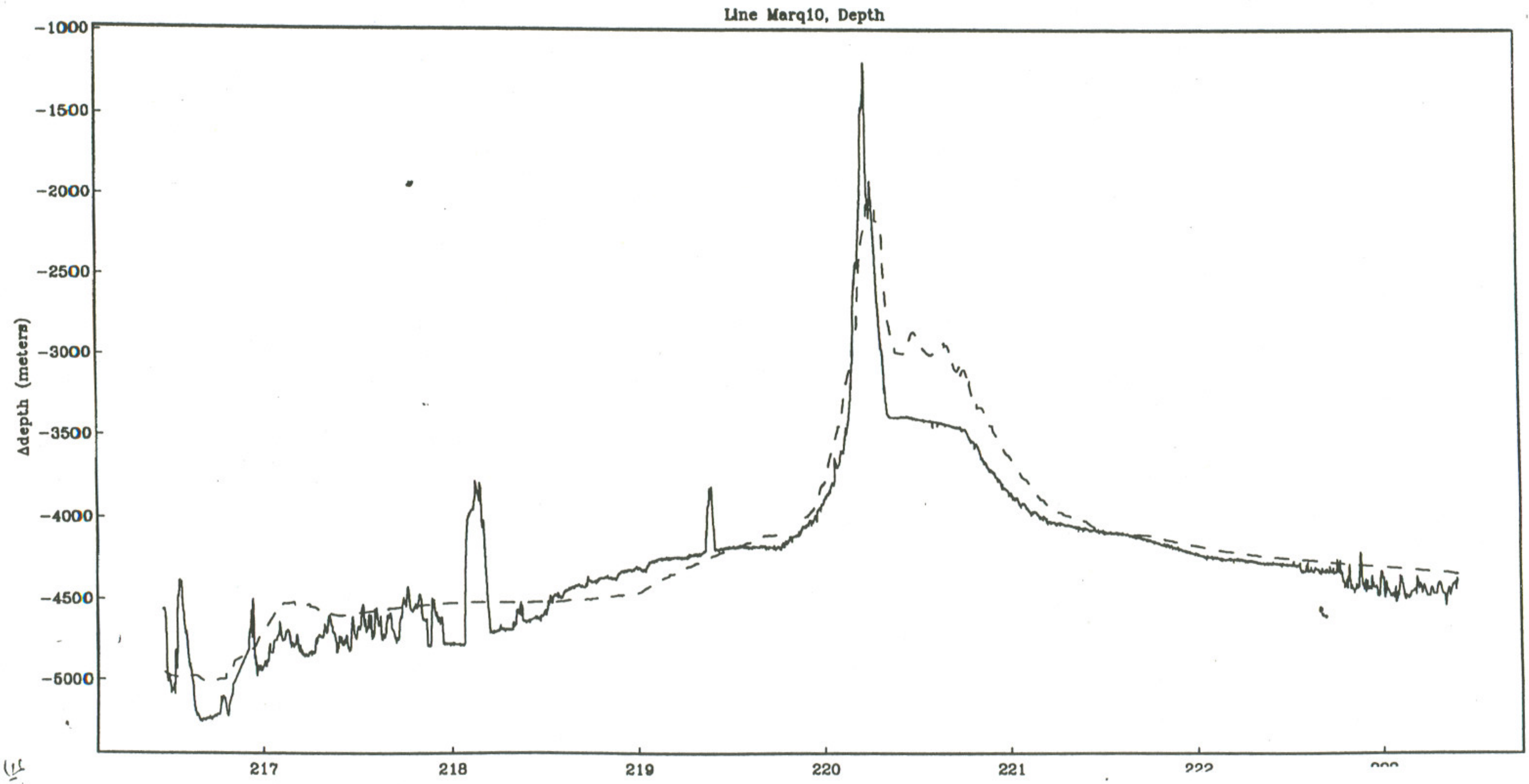


Fig 3

Comparison of Ship data to dbdb5



comparison of
ship data to
dbdb5

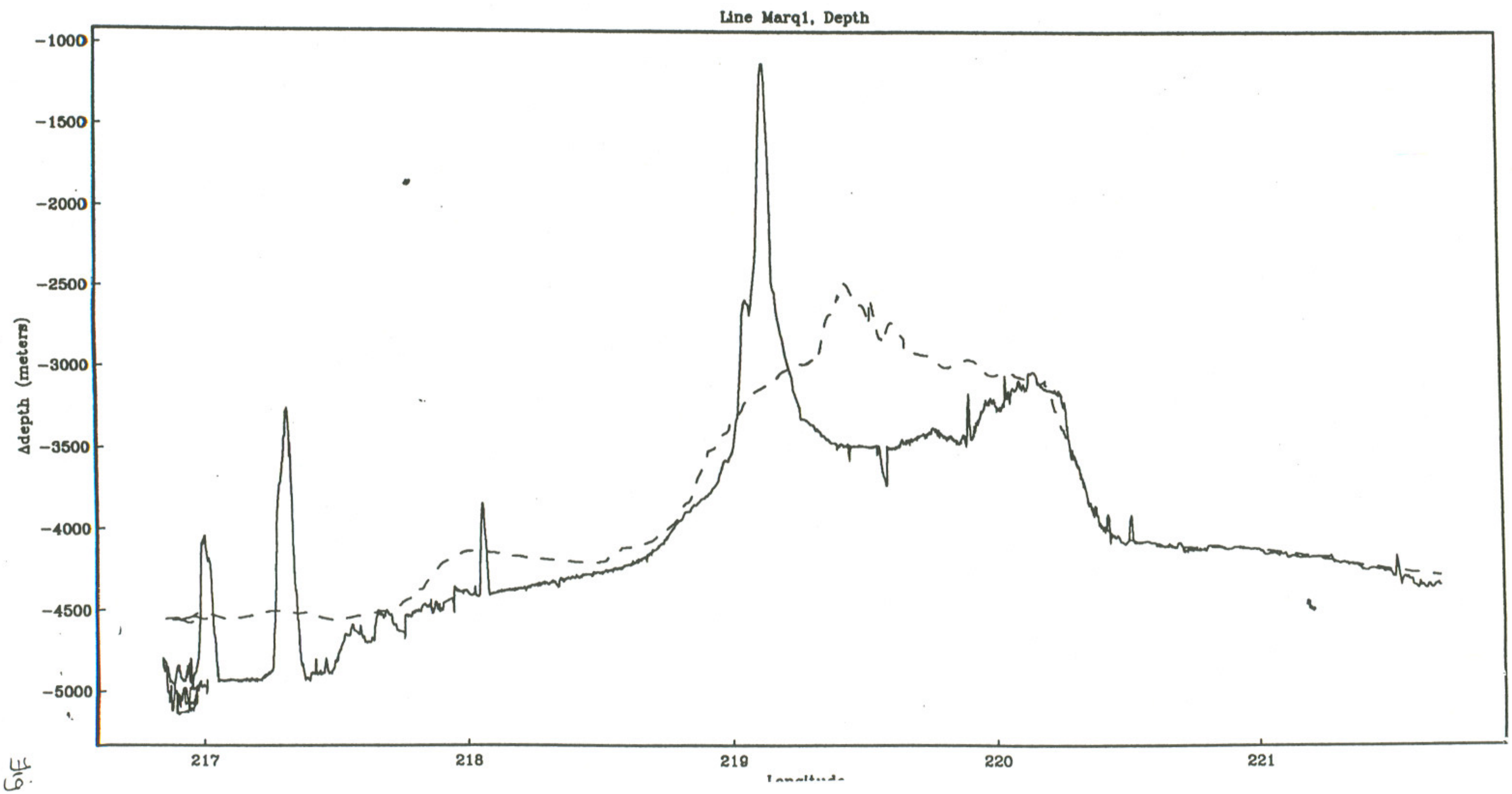


Fig.

Te = 17
ρ_o = 2650
nterms = 5
Z_t = 4.286

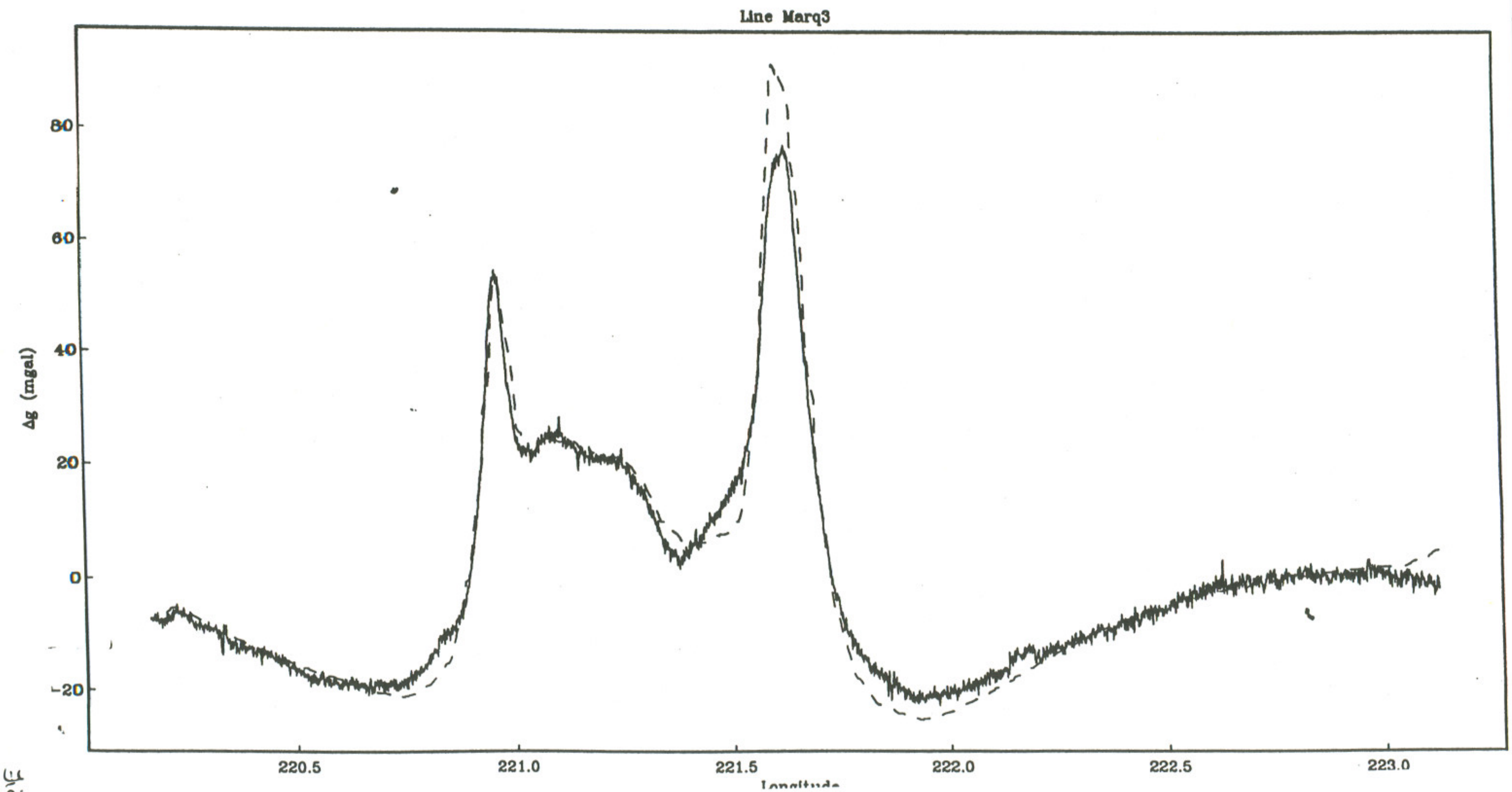
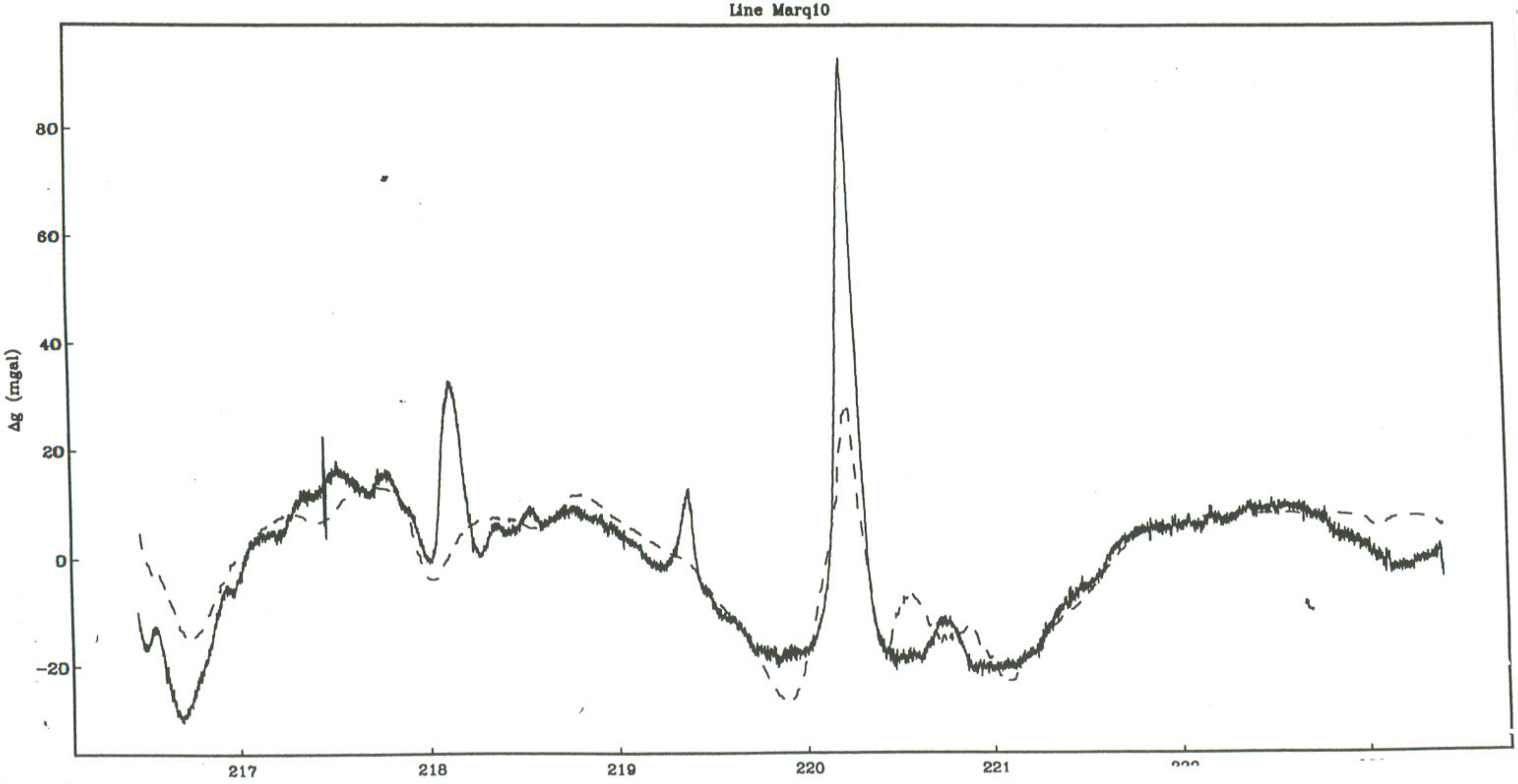


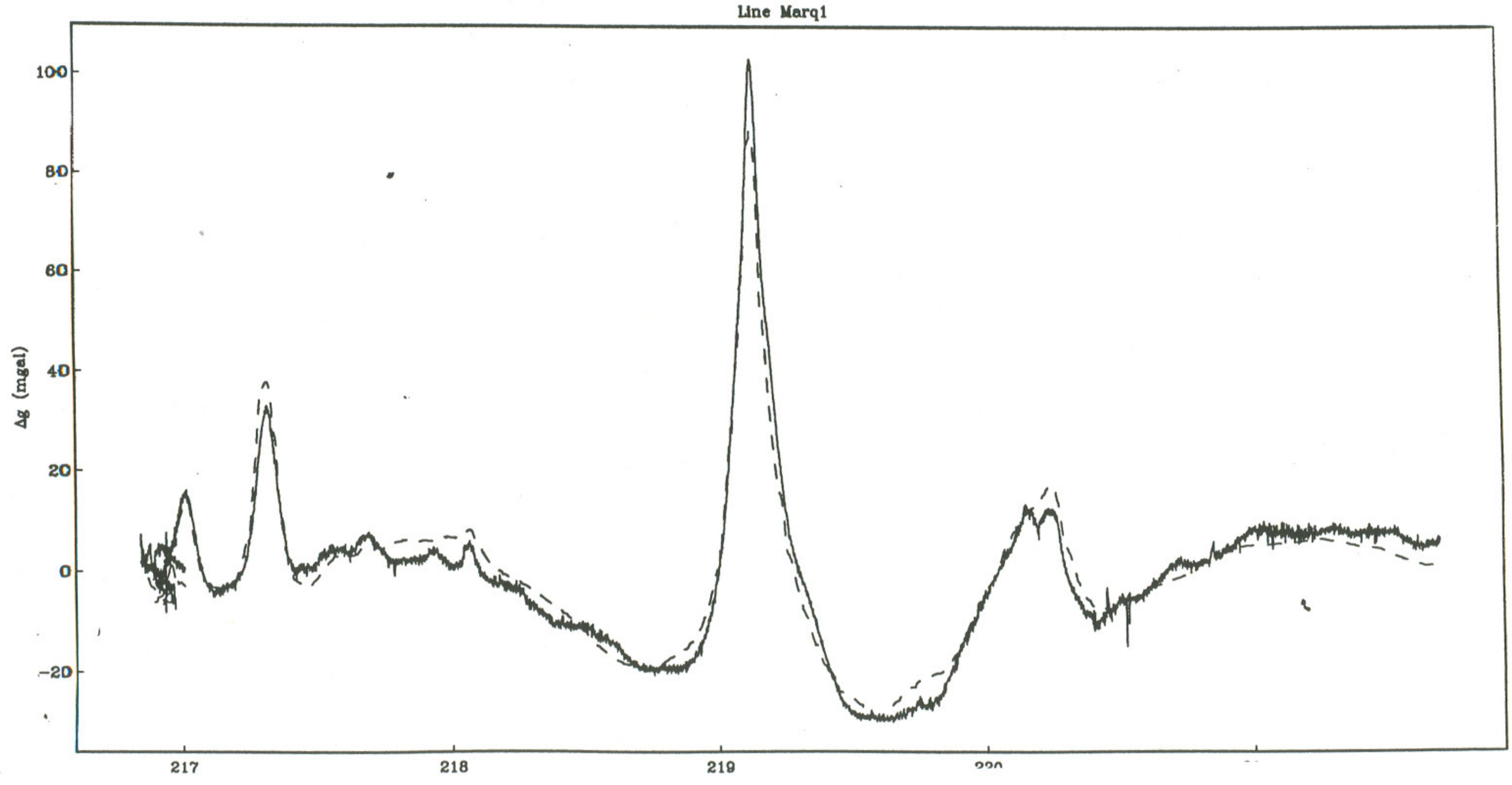
Fig 1

T_e = 17 k
ρ_o = 2650
nterms = 3
z_t = 4.28

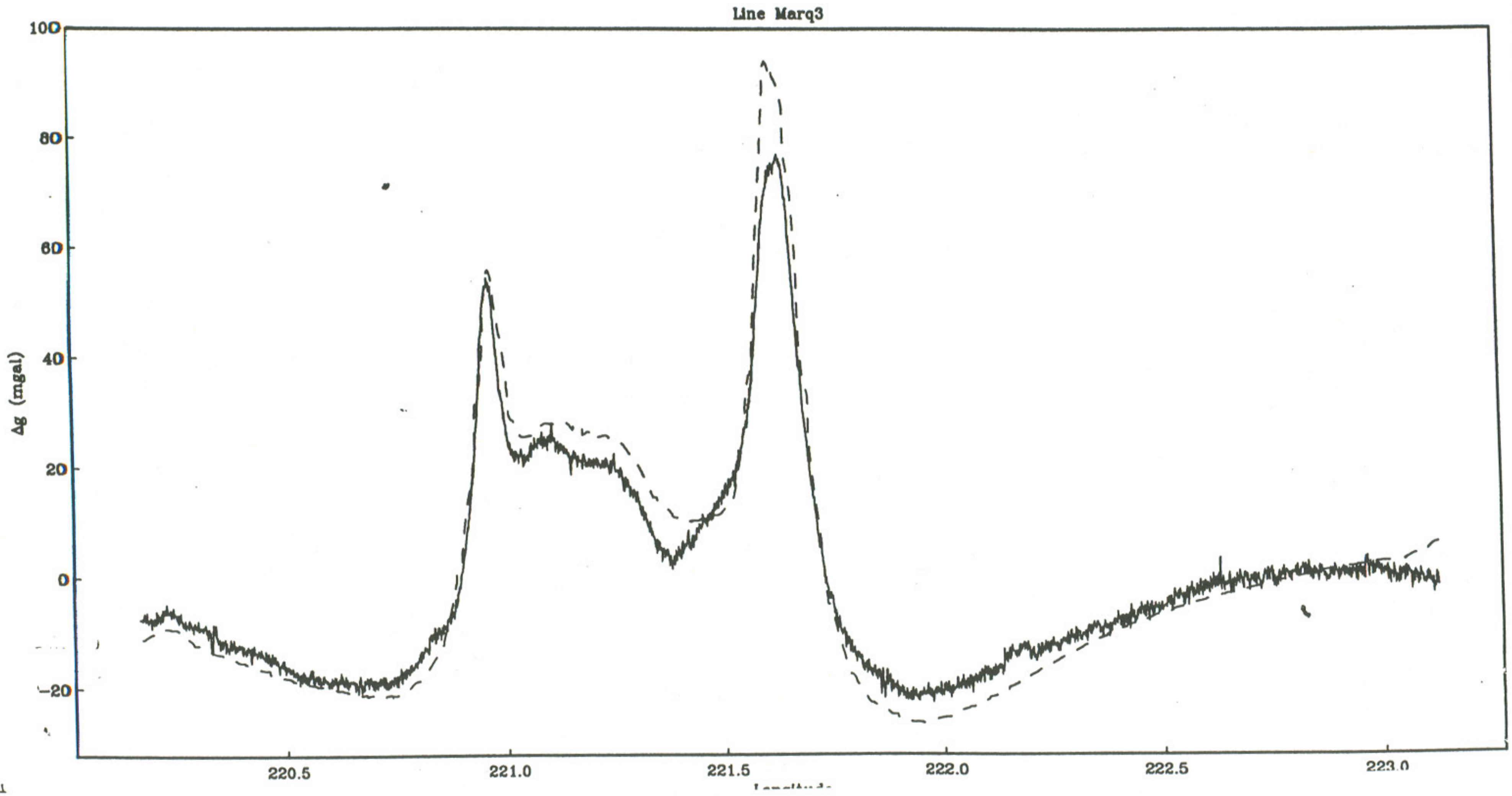
Line Marq10



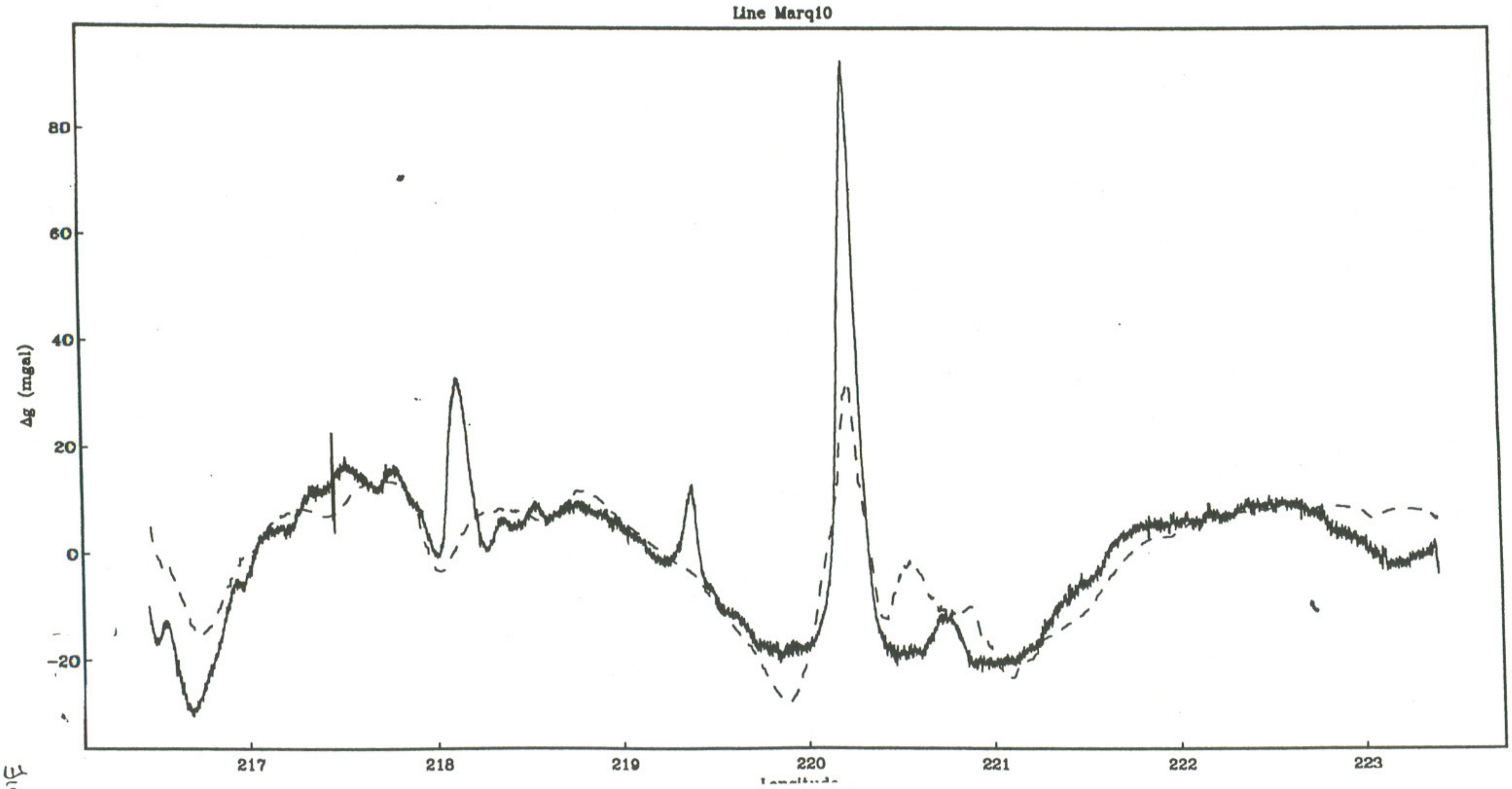
Te = 17 km
ρ_0 = 2650
nterms = 5
z_t = 4.286



Te = 20 km
ρ_0 = 2650
nterms = 5
Z_t = 4.286

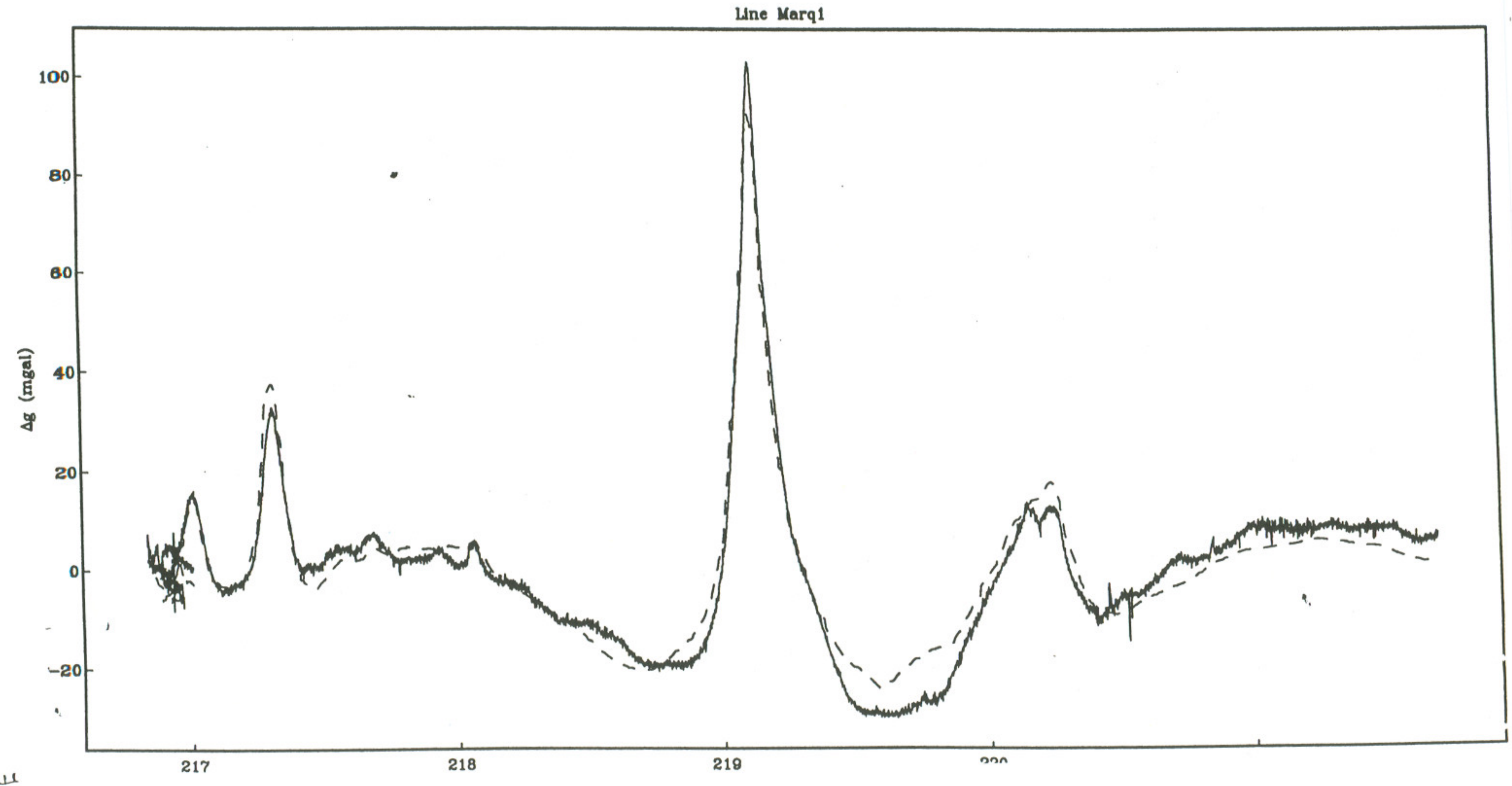


$T_e = 20$ km
$\rho_0 = 2650$
nterms = 5
$Z_t = 4.286$

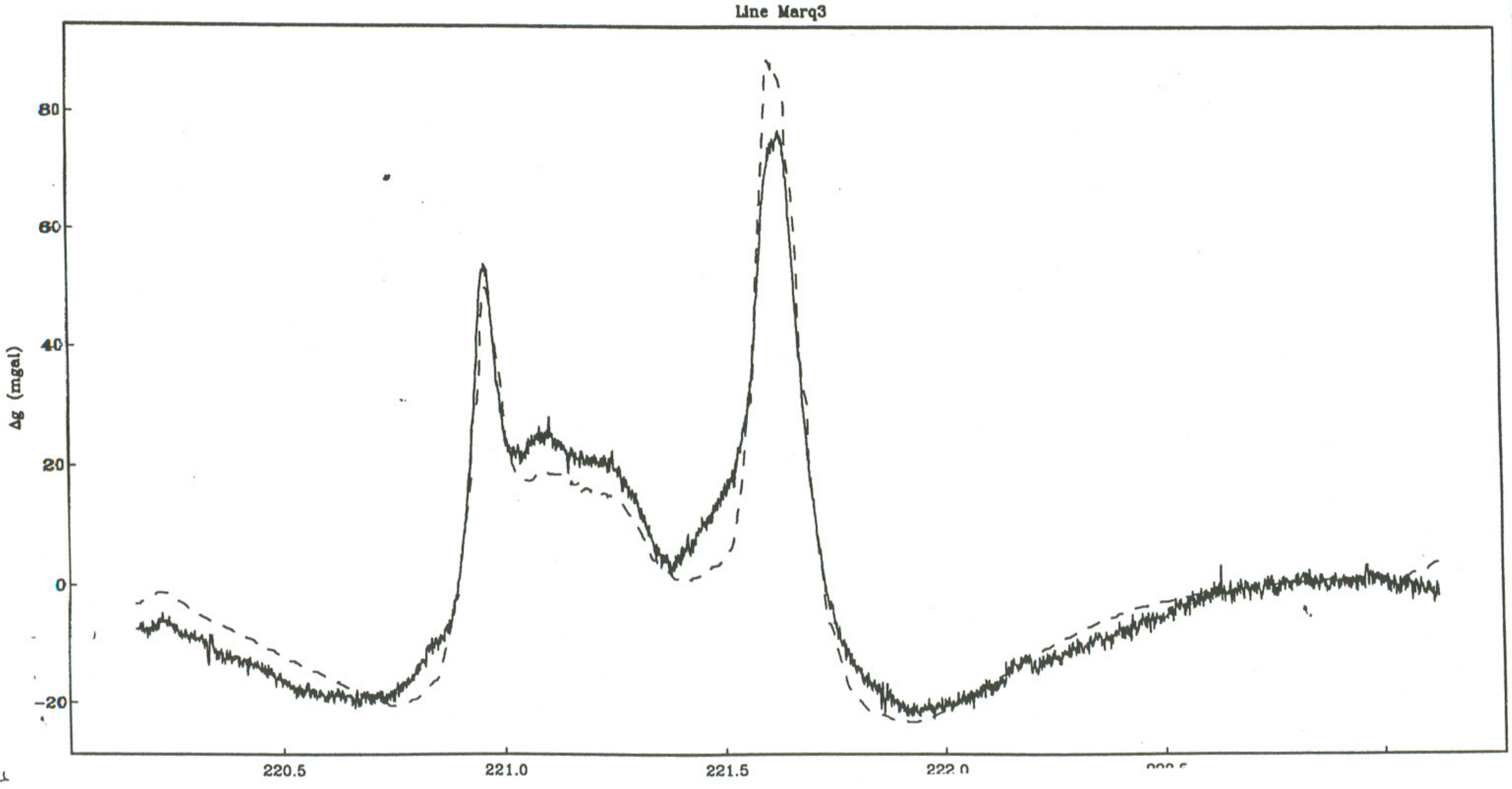


Fig

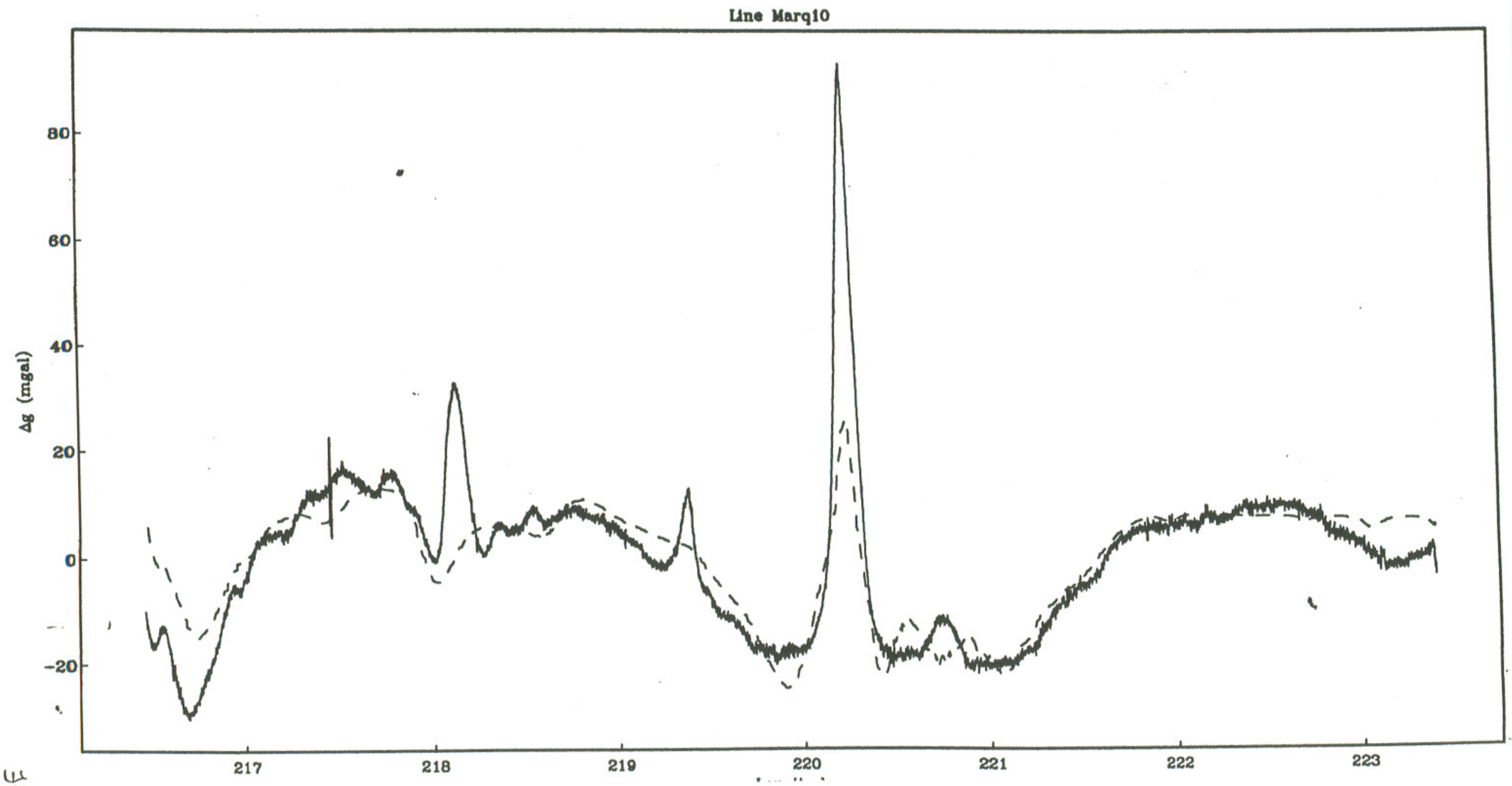
Te = 20 km
ρ_o = 2650
nterms = 5
ε_t = 4.286



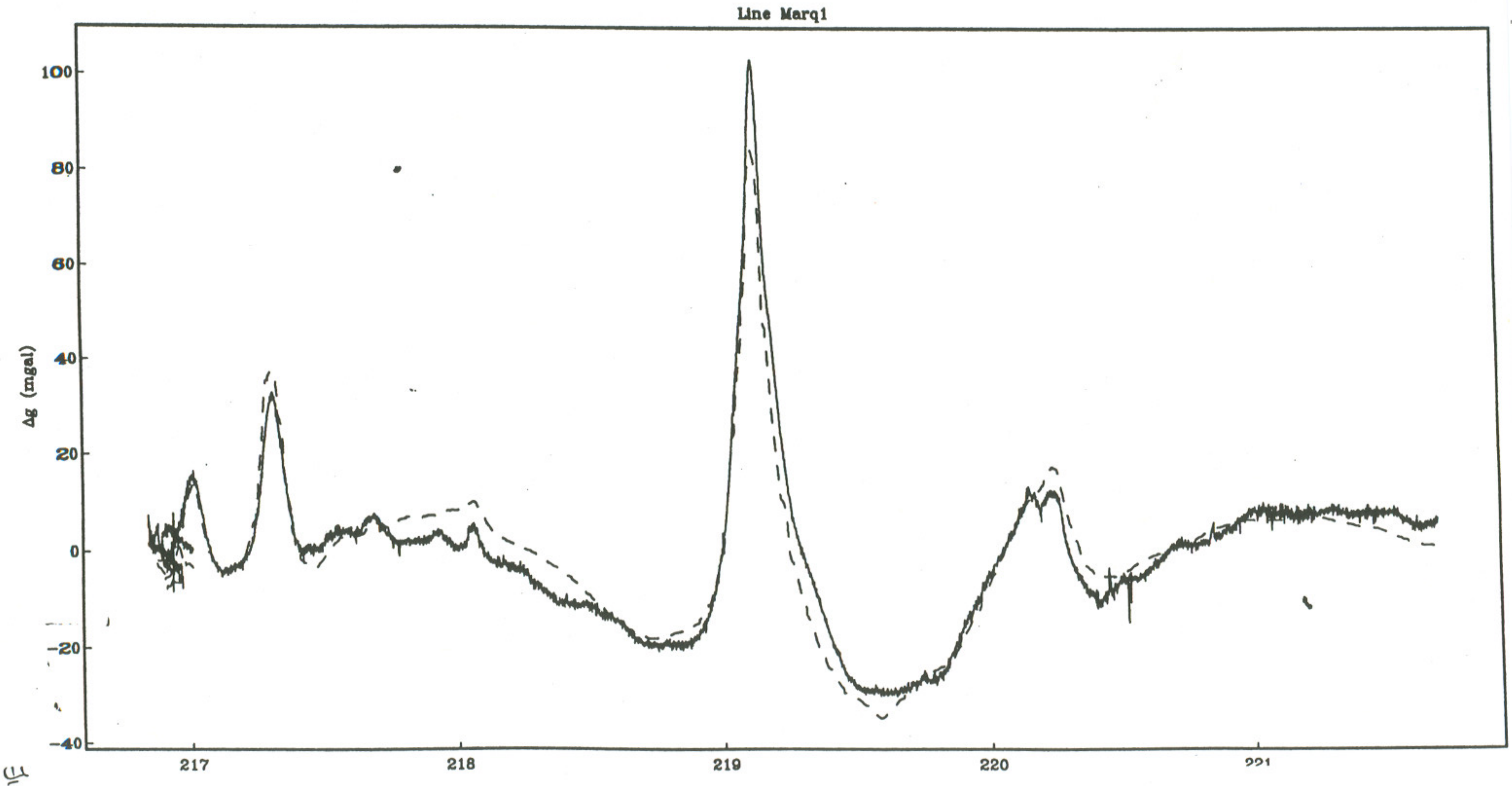
Te = 14 km
ρo = 265
nterms = [illegible]
Zt = 4.[illegible]



Te = 14 km
ρ_o = 2650
nterms = 5
ε_t = 4.281

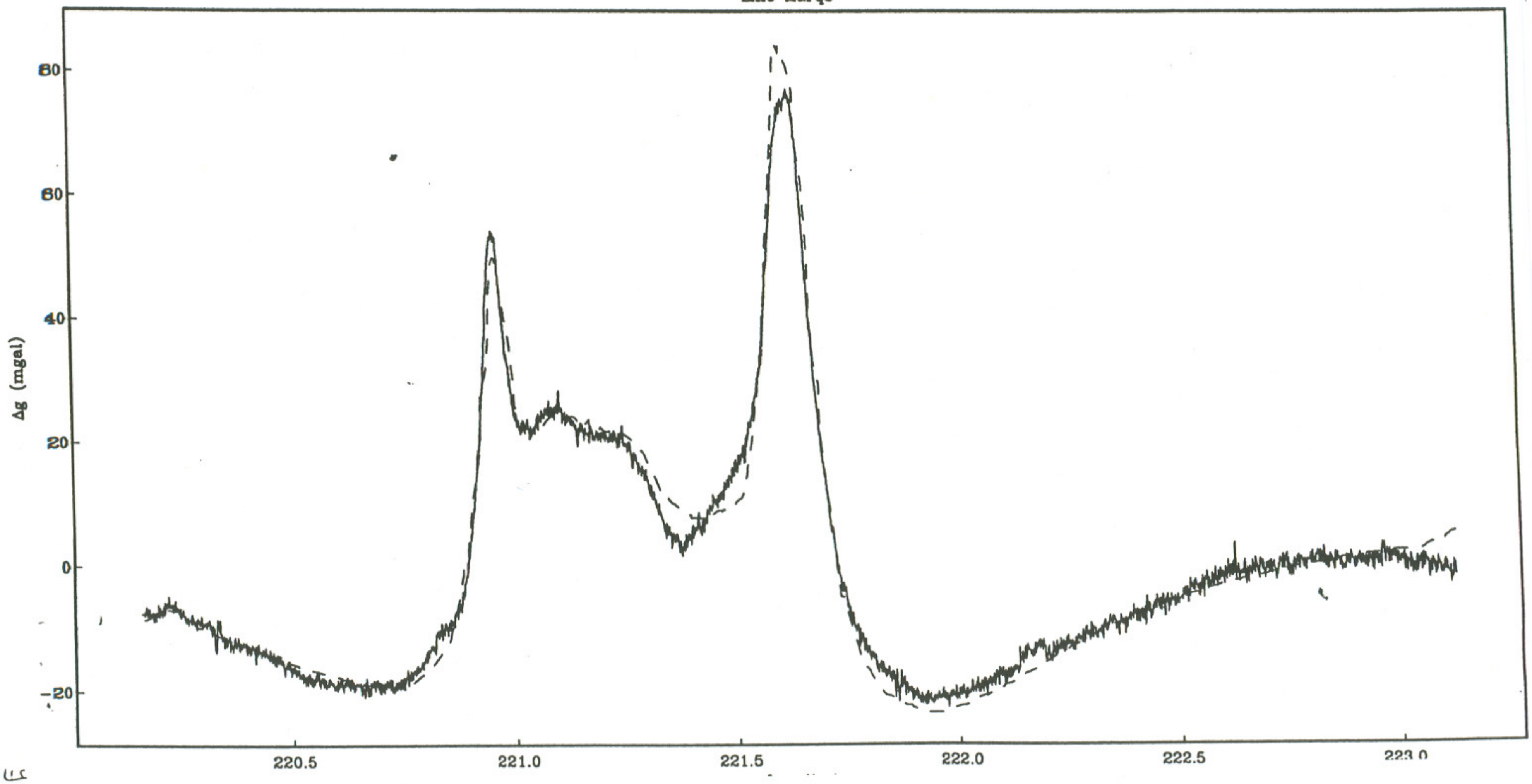


Te = 14 Kr
ρ₀ = 2652
nterms = 5
Zt = 4.286



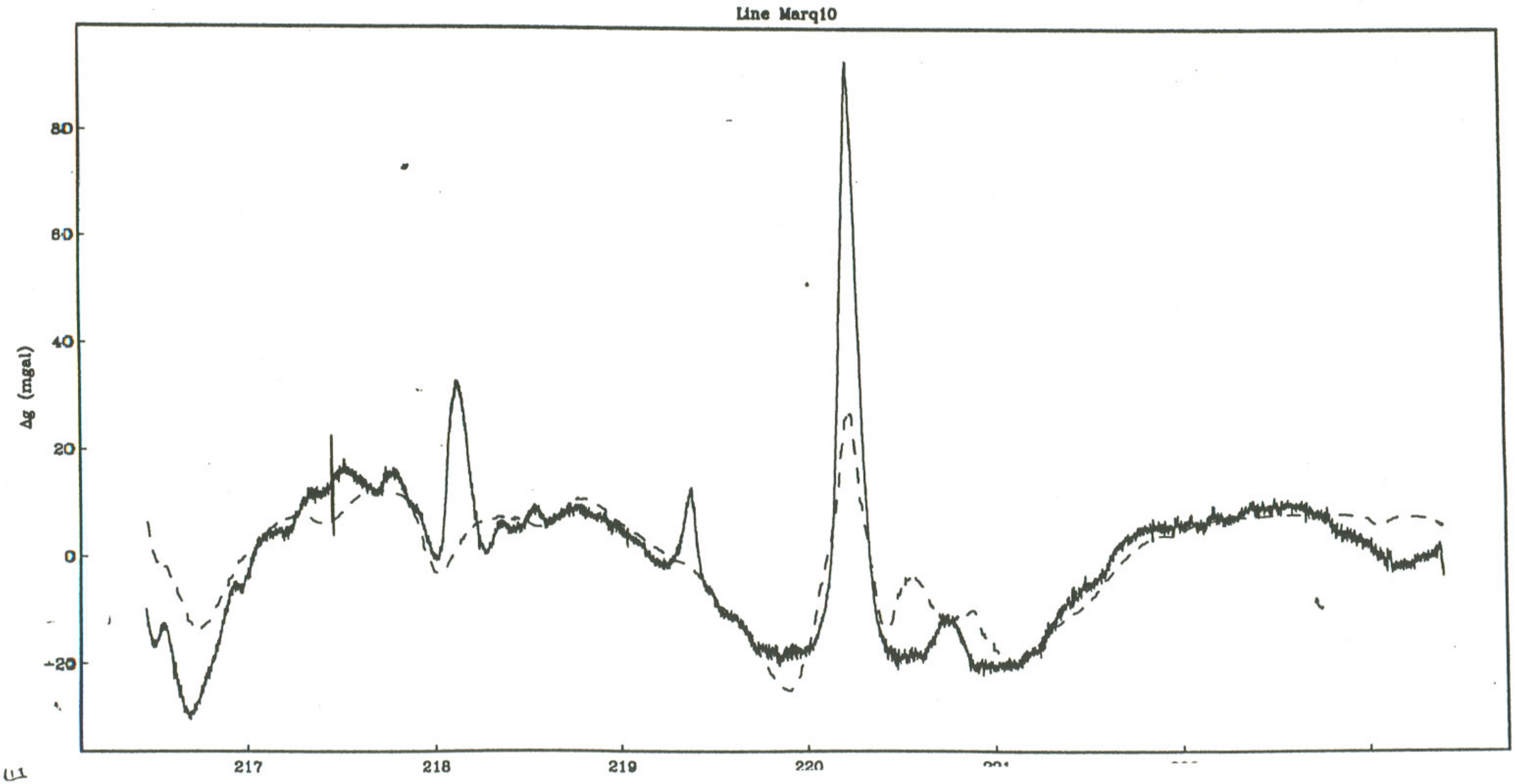
$T_e = 20$ km
$\rho_0 = 2500$
nterms = 5
$z_t = 4.286$

Line Marq3

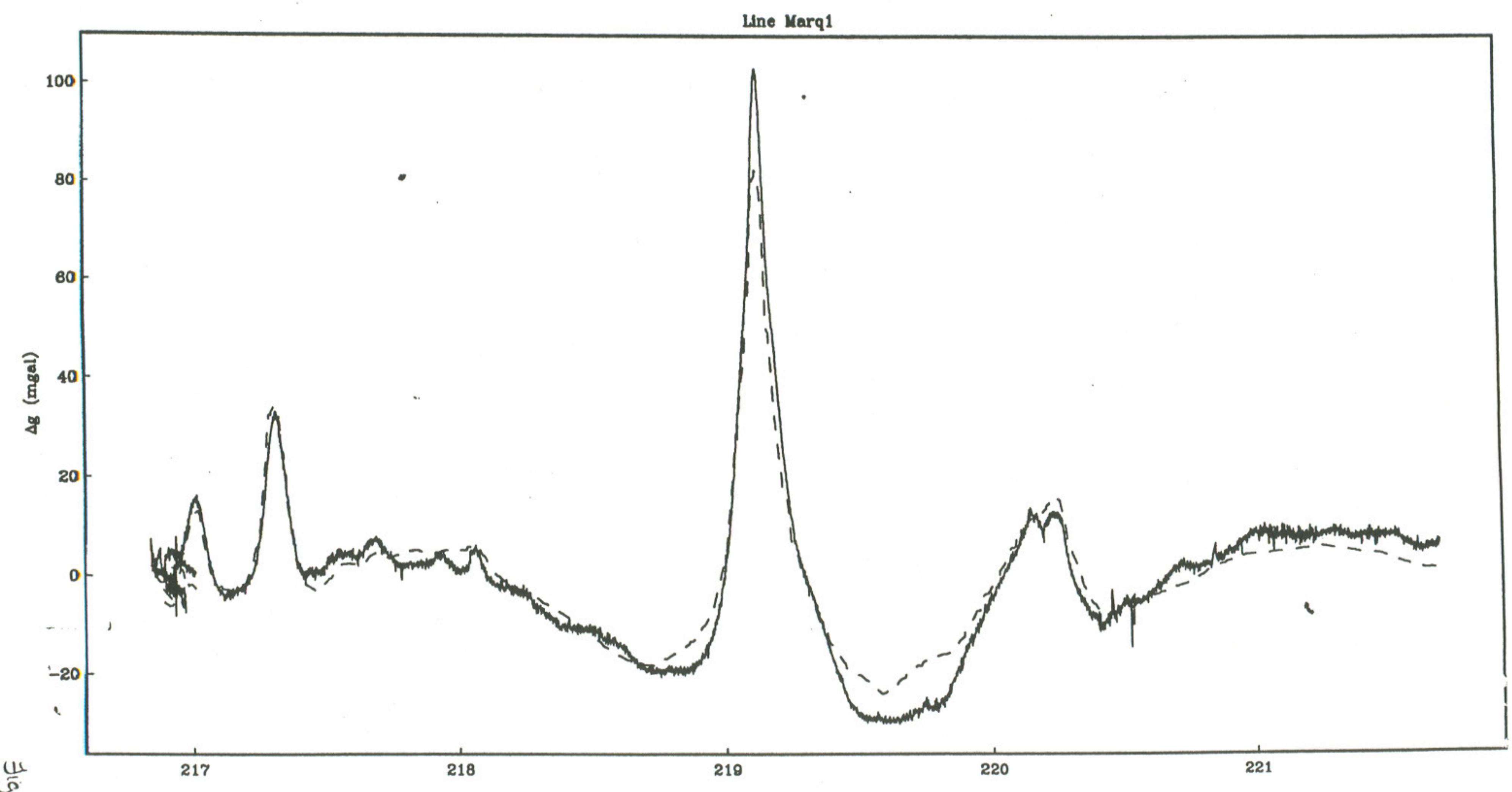


T_e = 20 km
ρ_o = 2500
nterms = 5
z_t = 4.28

Line Marq10



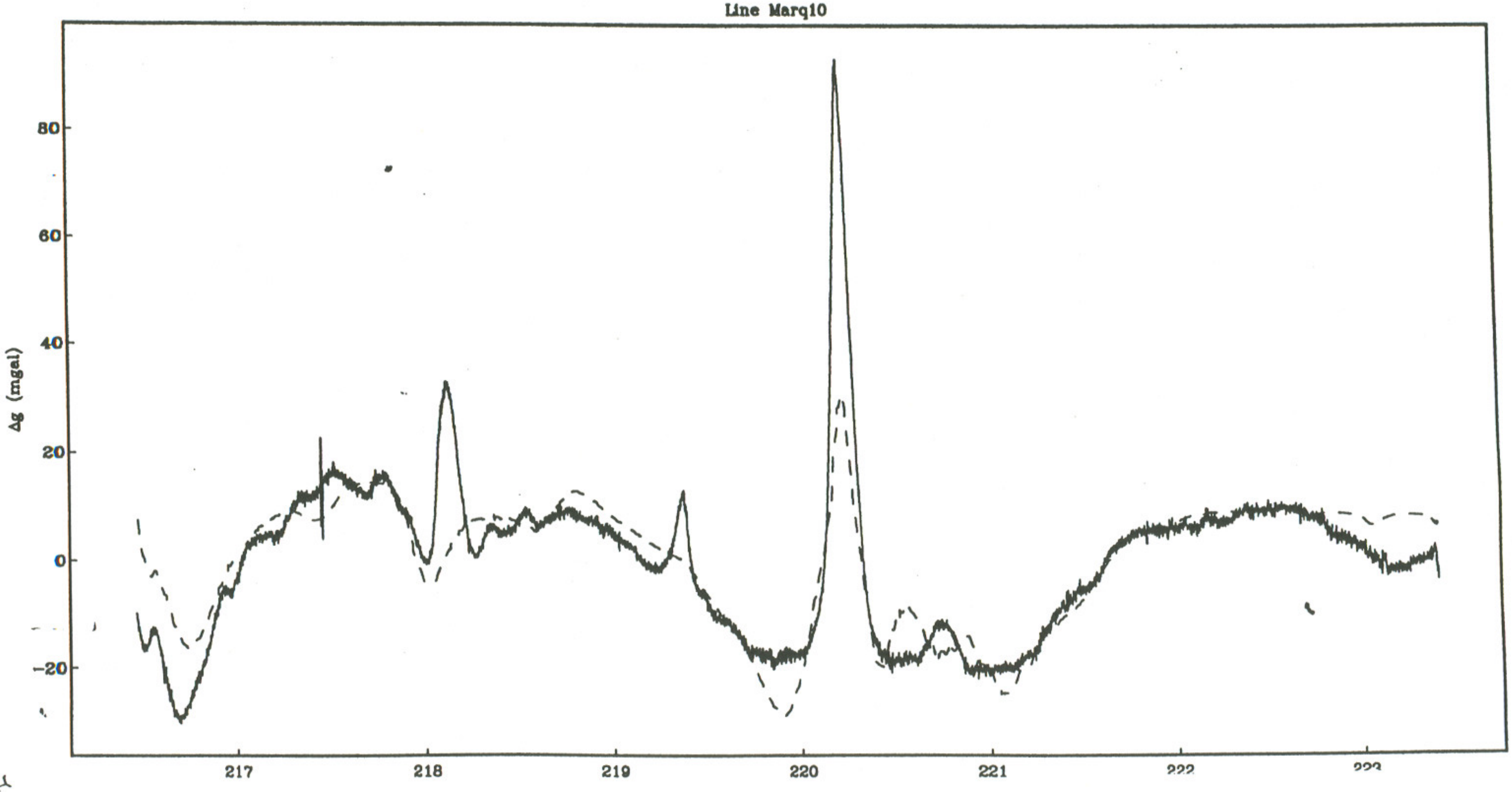
Te = 20 km
ρ_0 = 2500
nterms = 5
z_t = 4.286



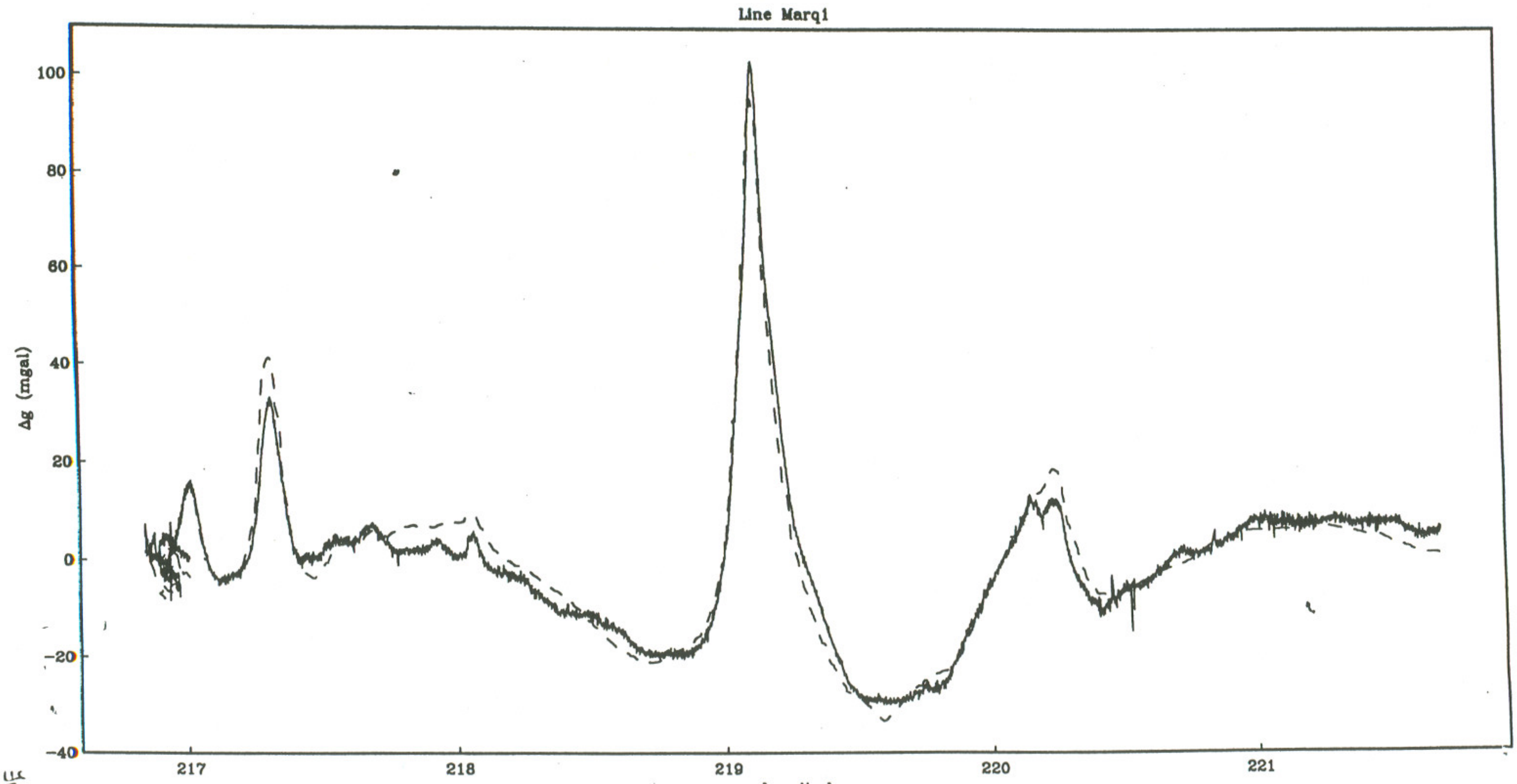
Fig

T_e = 15 km
ρ_o = 2800
nterms = 5
Z_t = 4.286

Line Marq10



$T_e = 15$ Km
$\rho_0 = 2800$
nterms = 5
τ_r : 4.286



Te = 15 km
ρo = 2800
ntermo = 5
Zt = 4.286