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Final Report

NAG5-240

Crustal Dynamics Studies in China

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Final Report for NGS-5-240

----------------- Geodynamics of China --------------------

Under NGS-240 the following research has been performed:

(1) the tectonics along the Tanlu fault in eastern China.

(2) tectonics in the Taiwan Strait behind the collision zone in Taiwan.

(3) analysis of faulting in the vicinity of the Altyn Tagn fault.

The major conclusions are:

I. Tanlu fault zone.

-- A major fault zone that extends from Dabie Mountains in Anhui Province in eastern China to the Bohai Gulf and then onto Amur River Valley in Siberia and disappears in the Okhotsk Sea.

-- The recent motion is definitely right-lateral from field evidence of stream offsets and focal mechanisms of small earthquakes along the fault. The stream offsets indicate that in the section of Tanlu in Southern Shantung Province the right-lateral offset amount to 25 meters. An offset of the old Yellow River channel at the town of Shouqian at the point where there are ample evidence of the presence of the Tanlu fault, the total right-lateral offset is about 25 kilometers.

-- Immediately south of the Yantze River south of the Dabie Mountains, the only evidence of the Tanlu fault is the right-lateral offset of a Ordovician/Silurian limestone unit; the total offset is less than ten kilometers.

-- The existence of the fault can be traces back to at least Jurassic with the deposition of conglomerate sandstones in the troungh along the present Tanlu fault branches in the Shantung Province. The Tanlu fault could be a part of the old plate boundary however; the wrap-around of the "Southern China Massif" at the southern end of the Tanlu fault is probably related to the left-lateral motion along the fault. If that is so then the left-lateral motion occurred in late Mesozoic and perhaps early Cenozoic and, judging from the left-lateral drag of the Dabie

Mountain metamorphics along the fault the total displacement can amount to 200-300 kilometer.

******* A partially completed manuscript is attached ******

II. Tectonics in the Taiwan Strait behind the collision zone. Taiwan is known to be the product of collision between the Philippine plate and the Asian plate. This collision is strong enough that its effect is felt in the Taiwan Strait and most probably across the Strait in Southeast China.

In the Strait young normal faulting striking nearly perpendicular to the trend of the Island is found.

In Southeast China, young basins bounded by NW striking normal faults started their existence in late Pliocene when Taiwan began to rise out of the ocean.

**** A partially completed manuscript is attached *****

III. Tectonics of Altyn Tagh Fault in northwest China. Altyn Tagh is a major fault bounding the northern edge of the Tibetan Plateau. The main branch has a length of about 1500 km. The eastern end of the fault is evidently left-lateral from stream offsets (Allen, 1981; Molnar and Tapponier,).

By correlating with the 1:4,000,000 geology map of China, we are able to identify the stratigraphic units correspond to most of the major features on the 1:750:000 LANDSAT false color images made with funds from this grant. By correlating a geological unit that appears on both sides of the fault, we estimate that the maximum displacement is on the order of 300 km.

There are a number of faults around the main branch. In general the formation of rhomboidal basins and the presence of push-ups at bends around the bends of the main branch along the part east of 82 east longitude are consistent with a left-lateral motion. However, near 80 east longitude the motion becomes dominantly compressional as shown by the presence of high ranges. Further to the west, the motion becomes right lateral.

It is interesting that in the western part of the Tarim basin, directly north of the area where Altyn Tagh fault becomes compressional, there is a major thrust in the Basin that is on top of a bulge under the basin. There some Late Paleozoic rocks, probably part of the basement of the Basin, is actually exposed. This structure in the middle of the Basin results evidently from the collision of Indian and the Asian plates.

**** Xerox copies of the LANDSAT images and their *****
**** interpretations are attached *****

The Tanlu Fault of Eastern China

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Introduction

Since Late Cretaceous and Early Cenozoic, there had been a notable change in the tectonics of Eastern China, most probably due to the impingement of India on Asian Continent and the subduction activities on the western side of the Pacific plate. The present Tanlu fault, cutting across much of China, was possibly the locus of tectonic activities since late PreCambrian. But the fault-controlled features are much clearer in the Post-Cretaceous rocks. With the occurrence of major earthquakes along this fault, the clear Quarternary geomorphic development, and the continuous occurrence of microearthquakes here, this is evidently a mojor structure in Eastern China.

The fault was not "discovered" until the late 1950's (Ministry of Geology, 1957; Xu, 1957). In the 1970's it became the center of attention in the study of the tectonics of Eastern China (Fang, 1979; Fang et al., 1979; Huang, 1977; Xu, 1980). But there are still many unsolved problems concerning the fault. The exact nature of its past activities, its extension to the north and the south and the total amount of displacement are all problems under continuous research.

This report provides an outline of the knowledge concerning this fault.

Location and General Geology

The geology of North China is markedly different from that of South China in several ways. It has long been for example that North China (Fig. 1) has a rather continuous sedimentary series prior to mid-Ordovician. Essentially no Devonian and Silurian rocks can be found there. The Sinian (PreCambrian) strata are commonly very extensive and thick limestone beds. And after mid-Ordovician scattered continental strata were formed. In contrast, the equivalent Sinian beds are mainly silty sandstones in South China. And Cambrian and Ordovian strata in South China were somewhat intermittent and from Silurian onward the near-shore deposits were laid down; only after Triassic did the marine sedimentation stop and replaced by sporadic continental sedimentation.

The section of the fault that has been studied in detail extends from the Bohai Gulf in Shantung Province to the eastern end of the Dabie Mountains in Anhui Province (Fig. 1) for a length of 1300km. The northern half of this section lies within North China, but the South China block wraps around the southern end of the fault. The fault evidently continues northward; it forms the eastern boundary of the broad Northeastern China Plain in Liaoning, Jiling and Heilungjiang (Fig. 1). Northward, there is a major fault that seems to link up with the Tanlu fault from Amur to the Okhotsk Sea according to available Russian reports(). Its southern extension is much more problematical, a number of tectonic interpretations (e.g.,Tectonic Map of China, 1980) depicts the fault as continuing across the Changjiang (Yantze River), through the South China block to end up in Gulf of Tonkin; however, this interpretation is not accepted by all. Thus the probable total length of the fault from Anhui Province to Okhotsk Sea is on the order of 2500 km.

Maximum Left-lateral Displacement Along Tanlu Fault

Because of the fact that the area has been uplifted above the sea level since late Paleozoic and the continental sedimentary cover either stripped from time to time or never had existed, it is difficult to piece together a complete story as is the case with the San Andreas fault. Such reconstruction has been attempted by Xu (1979 for example), but the correlation of strata across the fault is never certain and therefore the conclusion that the left-lateral movement of 700 km might have taken place during the Mesozoic has been subjected to much discussion (Fang et al.,1979; Wu et al., 1981 among others).

That Tanlu is an old boundary is clearly shown by the fact that the rocks on two sides of the fault in North China are not correlatable even allowing major horizontal movements. Thus the

Dabie metamaorphics near the southern end of the fault is butting against rocks of the "South China Platform", and the Archaen rocks of western Shandong are compositionally different from the metamorphics in eastern Shandong. The post Mesozoic sedimentary basin in eastern Shandong have not counterparts in western Shandong. But whether we could define this generalized boundary to have always been the Tanlu fault is questionable. As shown by McElhinny et al. (1982) that during Permian the North China block and the South China block may be totally apart and both were near the equator.

The existence of the Tanlu fault in North China since Mesozoic is certain. It is marked by the presence of two clear narrow valleys in which very characteristic Late Jurrassic and early Cretaceous strata were found. These are conglomaratic sandstones and coarse sandstones. The presence of these rift valleys implies tensile stresses normal to the fault.

The left-lateral movement has taken place is supported by several geological observations. The Dabie metamorphic complex for example is very very characteristic in the region. It is mainly found along the trend of the Dabie Mountains. However, it is found strewn along the Tanlu fault in Central Anhui Province. The farthest distance where the Dabie Mountain complex is found is about 200 km from the Dabie site. Actually,

Neotectonics and Seismicity

Neotectonic feature along portions of the Tanlu fault is very clear. Figures x-x show typical outcrop along the Shandong-Jiangsu section of the fault. This is also the location suposedly of the 1686 M=8 earthquake.

Fig. shows typical outcrops of the fault in Shandong Province near the town of Juxian. Left-lateral stream offsets amount to 20 m can be seen on the ground and in the airphotos. Some thrusting is also evident in some outcrops (Fig.).

The maximum right-lateral displacement that can be conjectured is about 25 km from the offset of one of the old Yellow River channels that crossed the fault in Jiangsu Province near the town of Shuqian (Fig.).

The effect of the right-lateral displacement is also clearly displayed by the post-Cenozoic deep graben east of the Dabie Mountain, along the Yantze River.

Conclusion

-- A major fault zone that extends from Dabie Mountains in Anhui Province in eastern China to the Bohai Gulf and then onto Amur River Valley in Siberia and disappears in the Okhotsk Sea.

-- The recent motion is definitely right-lateral from field evidence of stream offsets and focal mechanisms of small earthquakes along the fault. The stream offsets indicate that in the section of Tanlu in Southern Shantung Province the right-lateral offset amount to 25 meters. An offset of the old Yellow River channel at the town of Shouqian at the point where there are ample evidence of the presence of the Tanlu fault, the total right-lateral offset is about 25 kilometers.

-- Immediately south of the Yantze River south of the Dabie Mountains, the only evidence of the Tanlu fault is the right-lateral offset of a Ordovician/Silurian limestone unit; the total offset is less than ten kilometers.

-- The existence of the fault can be traces back to at least Jurassic with the deposition of conglomerate sandstones in the troungh along the present Tanlu fault branches in the Shantung Province. The Tanlu fault could be a part of the old plate boundary however; the wrap-around of the "Southern China Massif" at the southern end of the Tanlu fault is probably related to the left-lateral motion along the fault. If that is so then the left-lateral motion occurred in late Mesozoic and perhaps early Cenozoic and, judging from the left-lateral drag of the Dabie Mountain metamorphics along the fault the total displacement can amount to 200-300 kilometer.

References

Figure Captions

Recent Collision and Its Effects In Taiwan and Its Vicinity

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Introduction

Taiwan is situated in the Western Pacific in between the Ryukyus and the Philippines. As it has been pointed out by many authors that Taiwan, unlike its island neighborsin the Ryukyus and the Philippines, is in a collision regime (see for example, Biq,1971; Chai, 1972; Wu, 1978;Bowin et al., 1978; Lin and Tsai, 1982). It is a rather young collision; the high (3000-4000m) ranges formed from Paleogene and Neogene sediments along the axis of the island, recent seismicity, and the rapid modern day uplifting of the marine terraces all atest to the vigor of this young collision process. Even with such a young geological phenomenon, however, there are still disagreements among the geologists and the geophysicists as to the location of the suture line, the configuration of the plate boundaries and the detailed interpretation of the tectonic environment before the collision. Much new geological and seismological data have come into existence in the last ten years and further refinement in the tectonic picture of Taiwan based on these data is useful in our understanding of mountain-building processes in general.

Much of the plains and the foothills areas have been mapped on 1:25,000 scale and drilling as well as geophysical profiling have been done through petroleum exploration works. However, the Mountainous areas, due to the inaccessibility and the lack of easily identifiable horizons, have not yet been studied in great detail; the main features are known but the boundaries of units are subjected to change as more work is done there. The geology of the eastern part of the Taiwan Strait has been studied thoroghly by the Petroleum Company on Taiwan, but only one report has been published (Sun, 1982).

It is not uncommon to apply the classic geosyncline theory to the study of tectonics of Taiwan (see discussions in Ho, 1982) and this interpretation is sometimes pitted against the plate tectonic interpretation. Actually, being a very young tectonic belt, Taiwan is an ideal place to study some of the details of mountain building processes; the sedimentary record is relatively complete and the forces that caused the mountains to rise are probably still at work.

This paper is directed at the (1) interpretation of parts of the sedimentary record in terms of our knowledge of the recent passive margin and the deformation in the forearc area, (2) a further look at the seismicity through stereoscopic diagrams and (3) interpretation of structures in the Taiwan strait and across the strait on the mainland side as a consequence of collision of the Philippine Plate with the Eurasian Plate in Taiwan.

Geological Environment

Reviews of the geology of Taiwan can be found in Ho(1982), Biq(1984) and others. Since most of the papers on the geology there are not widely available outside of Taiwan, we shall summarize here the pertinent geological data germaine to our discussions.

Geographically, Taiwan can be divided into four distinctive sub-areas along nearly north-south lines. A narrow Longitudinal Valley divides the main part of the island from the Coastal Ranges on the east. These are ranges of about 1000 m in elevation and ringed on the east side, facing the Pacific, with raised marine terraces. To the west of Valley, the land slopes rapidly upward into the Central Mountains. Within a distance of about 30 km, the main ridge, much of it above 3000m, is reached, and the highest peak on the ridge has an elevation approaching 4000m. The Central Mountains grade into the Foothills to the west and then to the flood plain. The Taiwan Strait between the island and the Chinese Mainland is fairly shallow at an average depth of 20 meters; the depth increases rather rapidly south of the Pescadores, a group of basaltic islands.

The oldest rocks in Taiwan are exposed on the eastern side of the Central Mountains. These include shists, gneisses, metamorphosed limestone and amphibolites. The parent rocks of these metamorphic rocks are limestones, clastic sediments and igneous rocks. Greenschist, serpentinite and amphibolite bodies in the eastern part of this belt have been recently studied by Ernst et al.(1981) and Liou(1981) among others. The ages of these metamorphic rocks is certainly pre-Tertiary, but the their ages have not yet been accurately determined. Based on available data, the oldest rocks have an age of 86 m.y.(Yen.). But a few deformed amonites found in these rocks place them in Permian. Of course it should be pointed out here that at Permian time, the area in question could have been in an entirely different place and it has since drifted (McElhinny, 1981) for distances up to 3000 km to reach the present location. These rocks most probably form the basement of the northern part of the main Island.

Overlain the metamorphic basement are the thick slightly metamorphosed marine argillaceous sediments that form the high ridges of the Central Mountains and their western flank. The metamorphic grades of rocks in this belt increases generally from west to east. They are Eocene to Miocene in age. It is common practice to discuss the geology of the Island in term of a east-west profile. But there are significant north-south differences, and these argillaceous rocks demonstrate this well. In the north, this Tertiary indurated to metamorphosed argillite belt consists of actually two belts, the western belt includes sandstone members and carbonaceous layers and interbedded basaltic flows, tuffaceous sediments and so on. But the eastern belt contains limestone or marly interbeds and lenticular conglomerate beds, although these are of limited occurrence. In the south, only the the argillaceous strata are found; they are judged to be of similar nature as the eastern belt in northern Taiwan. The boundary between the north and south sub-provinces is marked on the map, but due to the lack of work in that area, the exact location is far from certain. It is interesting to observe that the boundaries of the eastern argillite belt in northern Taiwan follows the faults well, but the internal boundaries of the western belt intersect the western limit of the belt. These rocks do not appear in southern Taiwan, but the basement rocks under the Coastal Plain are perhaps the extension of these units (Chiu, 1975). In the south, the Eocene slate also is found to the east of the Pre-Tertiary metamorphic rocks west of the Longitudinal Valley.

The mechanically incompetent rocks in the eastern slate belt is severely faulted and folded with extensive development of slaty cleavage. The fold axes trend in the north-northeast direction. The rocks in the western belt however are markedly less deformed. That these two sedimentologically and structurally different rock units are juxtaposed means that the eastern belt was probably placed there after significant horizontal displacement and that the boundary is probably a fault, the Lishan fault, although the existence of this fault is not undisputed(Chen,).

To the west of the Central Mountains, a suite of Middle Miocene to early Pliocene shallow marine to shelf-clastics form the bulk of the foothills. Alternating sandstone and shaly layers dominate. In general the sediments contains more fine muddy matrix as one goes south and the strata are much thicker. Lenses of tuffaceous rocks, resulting from submarine pyroclastic eruptions of basalt, are present. The total thickness of the sedimentary rock reach 8000m to the east and decreases to less than 1000m in the west. In northern Taiwan, there are several coal-bearing layers; these are absent in the south, and the rocks contain a high proportion of mud. There is a drastic increase in the thickness of late Miocene to Pliocene strata south of 23.5 latitude (Ho, 1981), marking probably the position of the contnental margin before the collision.

The eastern edge of the Coastal Plain is festooned by a chain of terraces formed from sandstones/shale and conglomerates. These Pleistocene to Holocene deposits represent tectonic molasse.

Detailed studies of sedimentary structures reveal that while the sediments deposited prior to late Pliocene were supplied from sources to the west, those after that period were supplied by sources to the east(Chou, 1973).

The rocks in the Coastal Ranges on the eastern side of the island are quite distinctive from those on the rest of the island. The oldest rocks that crop out Miocene volcanics, mainly andesitic flows and pyroclastics. One magmatic suite seems to be an old eruptive center to the two islands, Lutao and Lanhsu off-shore to the southeast (Figure). Indeed, this center appears to line up with the two islands along an undersea ridge (figure), indicating perhaps that at one time they were all active and had the same role in the tectonic regime. A layer of agglomerates, tuff, and tuffaceous sediments underlies much of the Coastal Range, in the north and the south; the age of these rocks range from early Miocene to Miocene/Pliocene as determined from nanofossils and planktons contained in the limestone lenses occuring near the top of the formation.

Geology of the Taiwan Strait is not yet well-known. The petroleum exploration in the eastern half of the Strait has produced detailed seismic and drilling data. However, so far only very generalized cross sections have been published (Sun, 19[illegible]2). According to Sun, widespread unconformity exists between Eocene and Oligocene and between Pliocene and Pleistocene strata.

Throughout Tertiary, several basins can be identified with local ridges separating the basins from each other. Growth faults have also been found to accompany the deposition. Major faults are sub-parallel to the axis of the present Taiwan while the recent normal faults are often nearly east-west in orientation. The NNE-SSW block faults resemble those that are found on other continental shelves (see for example, Poag, 1982). Little has been said about the more recent (Pliocene-Pleistocene) environment in the Strait, although apparently the structural trends differ from those in the earlier basins and the intensity of tectonic movement decreases toward the west.

The foregoing discussion can be summarised in two schematic cross-sections, one for the north and one for south Taiwan are shown in figure together with a reconstruction of might have been before the mountain building. The Tertiary sediments in the Central Mountains and the foothills were deposited in basins on what was at the time a passive continental margin, a 200 or so kilometers wide shelf. As shown in figure , the shelf in early Tertiary probably went through the present day midpoint of the Island. In other words, the northern half of the Island was on the shelf, and the southern half of Taiwan was then the continental slope and part of the abyssal plain. The rocks in the eastern slate belt, phyllites and slates with limy components, may actually be mainly slope and apron sediments that were subsequently tectonically emplaced onto the shelf next to the shelf-deposited western belt(see further discussion later).

Geologic Structures of the Island

Off-shore Geologic Structures in the Taiwan Strait

We have mentioned the older structures in the last section. The multi-channel data must contain rich information concerning the neotectonics in the Strait. However, the data is not available for study. Lee (1973) however, has reported on the single-channel reflection profiles in the eastern half of the Taiwan Strait. Two nearly parallel reflection lines were run. It is evident that some of the on-shore faults are extended into the strait. But it is also clear that there are two basins, the Taichung basin and the Hsinchu Basin that are bounded by a number of normal faults that cut through the youngest sediments and are probably still active. The faults on the northern and southern edges of the Penghu platform are particularly clear. As we shall see that the Strait has infrequent, but very large earthquakes, and some of these faults are probably related to the seismicity.

Seismicity

The area under consideration is seismically very active. Katsumata and Sykes(1969), Wu(1970,1978) among others studied teleseismic data compiled by USCGS, NOAA, USGS and ISC and interpreted the data in terms of modern-day plate tectonics in the area. Recent maps published by Tsai and others(e.g., Tsai et al., 1982; Lin and Tsai, 1982) use data from the Taiwan telemetered network; although the main picture emerges from the regional network remains the same, the data provides more details in the immediate vicinity of Taiwan, especially in clarifying the relation of the Benioff zone under the andesitic volcanoes in the extreme north of the island and the thickness of the seismically active layer.

The spatial distribution of hypocenters(data from the USGS PDE tape and the ISS Bulletins) can be seen in a series of stereoscopic perspective plots(figure). Clearly, no Benioff zone exists in the section of Taiwan between the northern and the southern ends of the Longitudinal Valley. On the other hand, the dipping seismic zone continues from the Ryukyus to the region northeast of the island. It is shown clearly in Lin and Tsai (1982) that this zone extends under the northern tip of the Taiwan island under the group of young andesitic volcanoes.

In figure the historical seismicity of the Taiwan and the continent across the Strait is plotted. It is interesting to note that several major earthquakes occurred in or off-shore of Fujian area. All along the eastern shore of China has been populated throughout the recorded history, thus the lack of large historical events elsewhere is not due to a lack of recorded history of those areas. Only magnitude six or smaller events have been reported elsewhere along the coast (Geophysical Institute).

Focal Mechanism solutions and Interpretation

A compilation of the available focal mechanism solutions is shown in Table 1.

Plate Configuration in the Taiwan Area

Figure depicts the plate configuration in the vicinity of

Taiwan as implied by geology, seismicity and focal mechanisms presented in the last sections. The main features are: (1) a collision boundary exists along the coastal range, the Philippine Sea plate exerts stress perpendicular to the boundary as well as slips along this boundary in a left lateral sense, (2) the Philippine sea plate

Faulting Behind the Collision Front

We have discussed so far several types of recent faulting west of the Longitudinal Valley. These represent faulting activities behind the collision boundary. The thrust faulting in the foothills is easy to understand as they are consistent with the direction of the tectonic stress that cause the uplifting and east-west deformation on the island. The repeated strike-slip faulting (e.g. associated with the 1935 Hsinchu and the 1906 and the 1946 Chiayi earthquakes) along nearly east-west trending faults, and the nearly east-west trending normal faults in the Strait are features that demand explanation.

Recent Faulting and Basin Formation in SE Fujian

No marine geology or seismic data in the western half of the Taiwan Strait is now available. However, there are some recent land data in Fujian Province across the Strait that indicates some young structural activities are taking place that may be a result of the intense collision in Taiwan. Figure shows the locations of several young basin in the coastal area (Zhang, 1982;Chen et al., 1980). These basins are controlled by north-west oriented normal faults. The Fouzhou graben is one of the largest basins in Fujian; according to drilling data, the subsidence started in Mid- to Late-Pleistocene and has now reached 100 meters or so, i.e. subsiding at an average rate of 0.3-0.7 mm/yr(Zhang, 1982). The 1604 earthquake, with an estimated magnitude 8 occurred in the Strait near Fouzhou.

The Santou basin further to the southwest is also controlled mainly by the northwest oriented faults; the basin contains vertebrate fossils of Late Mid-Pleistocene, stone-age tools etc. It is clear that during Quarternary, this area has undergone several episodes of rapid subsidence; the earthquake of 1918 (M=7.5) was apparently related to a NW oriented fault (Zhang, 1982).

Until marine seismic data in the Taiwan Strait becomes available, the continuity of tectonic fabrics from Taiwan to Fujian cannot be ascertained. However, the occurrence of large earthquakes in the Strait, the presence of east-west to northwest oriented faults on both sides of the strait, and the presence of numerous normal faults in the eastern half of the Strait (Lee, 1974) all point to the possibility that these structures are genetically related. These faults, at high angles, with the colission boundary, have been observed at several places. Molnar and Tapponier (197) have particularly point out the presence of such a structure behind the Himalayas in southern Tibet.

Discussion

The recency of the orogeny that is found on Taiwan affords us a chance to examine some of the details of tectonic processes that had taken place. With the general agreement that collision is responsible for the conversion of a continental margin into an impressive mountain range does not preclude disagreement regarding the collision boundary nor does it imply that the major geological observations have been adequately understood in terms of plate tectonics. We shall attempt here to offer explanations for some of them.

The argillite belts in the Central Mountains have been interpreted as the result of marine transgression into the "Taiwan Geosyncline". But the juxtapositioning of two very diverse sedimentary units, the eastern belt that contains limy and marly layers and the western belt that contains carbonaceous sandstones, implies that major tectonic action had brought them together.

The Philippine Sea was most probably an expanding basin in early Tertiary (e.g. Lee and Hilde, 1982;), although the exact location of the ridge and mode of spreading is not yet totally clear. Thus the continental shelf of southeastern Asia at that time could resemble the Atlantic margin during late Cretaceous and the present-day Atlantic margin can be viewed as a model of the pre-collision depositional basin in Taiwan area (figure). From Eocene to early Pliocene, the edge of the shelf probably subsided continuously and the sediments lapped farther and farther onto the adjacent floor (figure). As the island arc approached the shelf, the depositional basin deepened. But the sediments on the ocean floor were compressed and pushed toward the shelf (figure). Since part of the sediments are on the oceanic crust and we know that the continental crust has now been thrusted up into mountains, with the island arc next to it, the sediments must have been telescoped onto the continental crust. And the eastern argillite belt could actually be these shelf edge to abysal sediments (figure). In fact, the "Cretaceous or early Eocene" corals found in the conglomerate bed intercalated in the lower part of the slate sequence in northeastern Taiwan (Ho, 1982) could very well be steep reef corals on the edge of the shelf that were plucked off by flow loaded with sediments.

Judging from (1) the positions of the Miocene volcanic complex in the Coastal Range and the offshore Miocene andesitic islands as well as the undersea ridge that connects these points, and (2) the existence of a dipping seismic zone under these islands, the collision of the island arc with the continental shelf started in the northern portion of the Longitudinal Valley and the collission in the southern half of the Coastal Range has not yet come into full force. Thus we expect that Lutao and Lanhsu to converge onto the eastern coast of Taiwan in the future.

Because of the oblique orientation of the continental shelf with respect to the approaching island arc, there is a distinctive difference between northern and southern Taiwan. In terms of the metamorphosed paleogene sedimentary rocks, in the northern part of the island we find shelf facies rocks, alternating sandstone and shale strata with carbonaceous layers, in the southern part we find deeper water facies, fine grained shale with marly nodules. Also, the Eocene slates appear only on the western side of the Paleozoic/Mesozoic metamorphic rocks in the northern half, a long strip can be found on the eastern side of the metamorphics in the south. In other words, projecting into the future, one could expect the further convergence of the rest of the island arc, now marked by the positions of Lutao and Lanhsu, and the southern portion of Taiwan.

Conclusions

Taiwan came into being because of a former island arc (the current Coastal Range)

Under Luzon a similar "reversed Benioff zone" exists, but Luzon does not have intense shortening — because there is nothing to collide with.

The collision forces are so intense near Taiwan that it is transmitted to areas west of Taiwan. In the Taiwan Strait, there are normal faulting perpendicular to the axis of Taiwan due to tensile stress behind Taiwan perpendicular to the direction of collision. Across the Taiwan Strait on the Fujian Province side there are a number of nearly northwest oriented basins that evidently started to subside at the time Taiwan rose out of the water to become an island.

At present, the island of Taiwan represents a cross-section as follows:

East of the Longitudinal Valley — Island arc and melange complex.

West of the Valley -- trench sediments thrusted over the edge of the old continental shelf (the Eocene argillites) and the miogeosynclinal sediments on the former shelf.

References

FAULTING IN SOUTHERN XINJIANG PROVINCE, CHINA

-- a Study based on LANDSAT images ---

The original figures are color false LANDSAT images. These have been processed at the JPL Image Processing Laboratory by Joseph Preisig, a graduate student in the Department of Geological Sciences, at SUNY Binghamton, under the guidance of Dr. Alan Gillespie. The numbers attached to each frame can be located on the index map.

The geology along the fault is obtained by comparison with the 1:4,000,000 Geology Map of China (1976, Ministry of Geology of People's Republic of China).

According to most Chinese geologists, the Altyn Tagh mountain ranges represent the site of a Paleozoic collision. There are many ultra-basic rock bodies on the Geology Map.

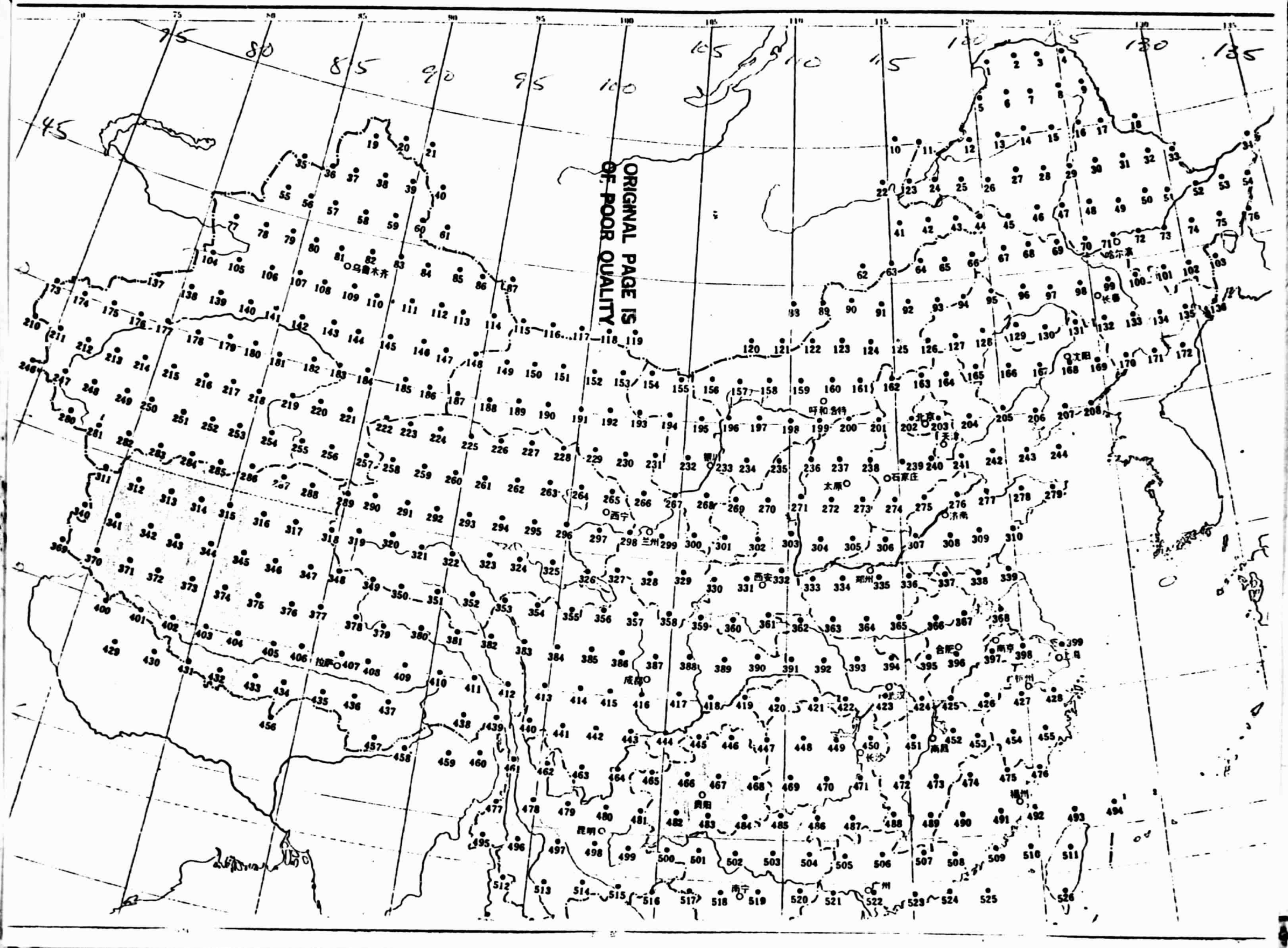

Figure 1. (189 on the index map.) This frame is located at the end of the Altyn Tagh fault, in the Province of Gansu. While Altyn Tagn fault is evidently a strike-slip fault west of this point (approximately at longitude 97 degrees E., the Qiliang fault to the southeast is dominanatly a thrust fault, leading to mountains with elevations reaching more than 5000 meters. The main city in the area is Yumen. The Sule River comes from the west into the frame AND fanned out before it becomes one and crosses the fault. At the fault the river valley has a clear left-lateral displacement, amount to about four to five kilometers. The 1932 Changma (the name of a small town) earthquake was located at the juncture of the Qiliang Mountains and the Altyn Tagh fault (39.7 N, 97.0 E, M=7.5). There is no evidence that the Altyn Tagh fault extends further to the northeast, beyond 98 degrees or so. This implies that the left-lateral motion is transformed into thrust motion here resulting in mountain-building.

FIG 1
189

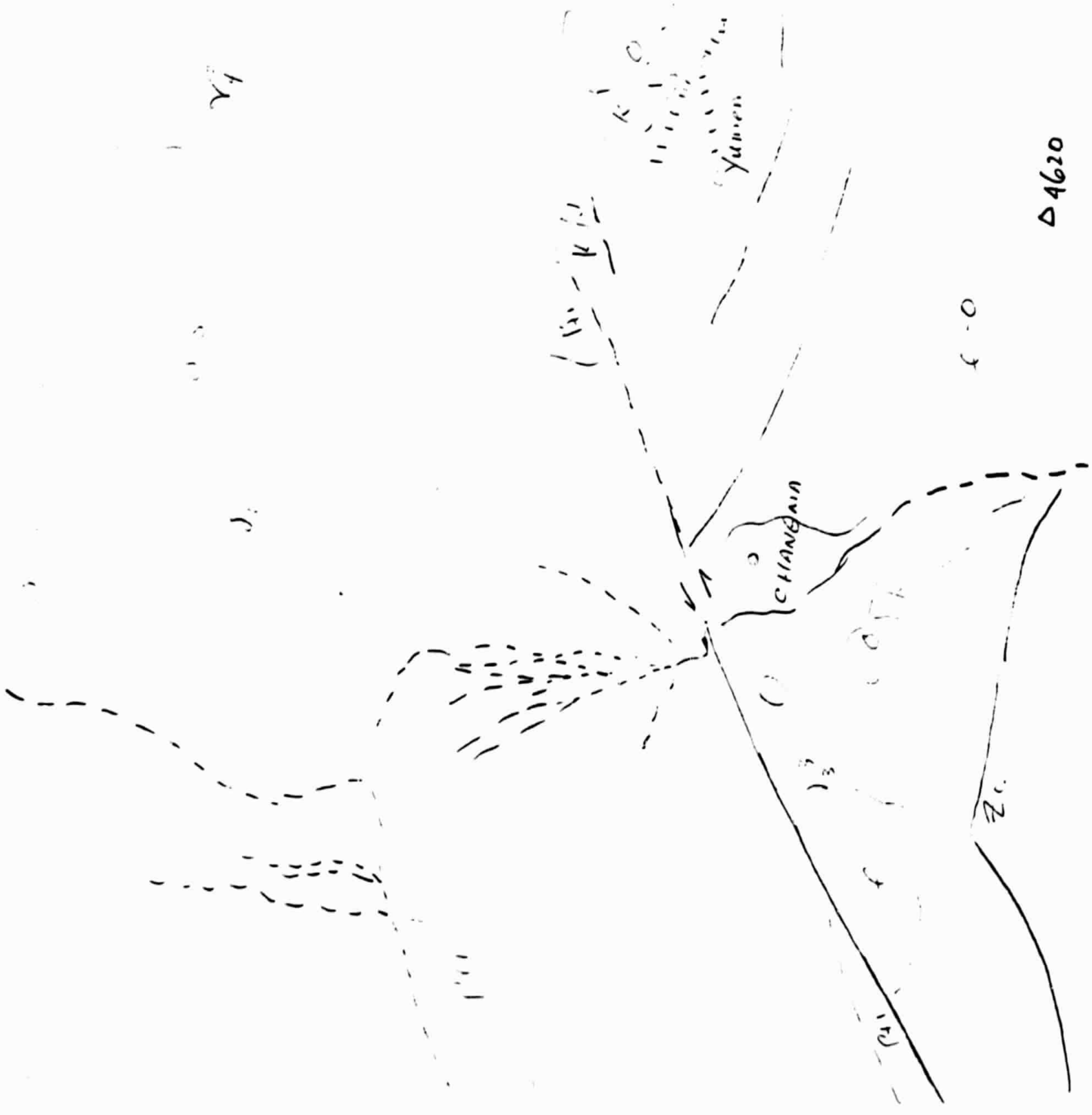


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Figure 2. (224 on the index map). The most impressive features on this frame is the presence of prominant curvature along the fault trace. As a result of the curvature, the Altyn Tagh, or the Altyn Mountain (the name sake of the fault) rises to a height of 5792 meters as result of the presence of a curvature at this point in such a way that the left lateral motion results in compression in the NE-SW direction. The Altyn Tagh is capped by ultrabasic bodies according to the Geology Map of China.

The southeast corner of the frame is still dominated by the Qilian Range. The Range is composed mainly of Paleozoic sedimentary rocks.

To the southwest, it is a part of the Qaidam Basin. It has an average elevation of 2500 m or so, somewhat higher than the Tarim Basin to the west-northwest. It is considered to be a "rigid block" in the Chinese literature. It is interesting that while the Altyn Tagh fault in contact with the northwestern boundary of this fault is fairly straight, the segment at the northeast corner of this block is curved, perhaps consonant with the idea that Qaidam behaves like a block in the overall deformation of the region.

To the northeast corner of the frame is a Paleozoic stratum that is of common occurrence along the fault. However it is very remarkable that this stratum for a distance of about 300 km appears only on the south side of the fault. See discussions on Fig. 3.

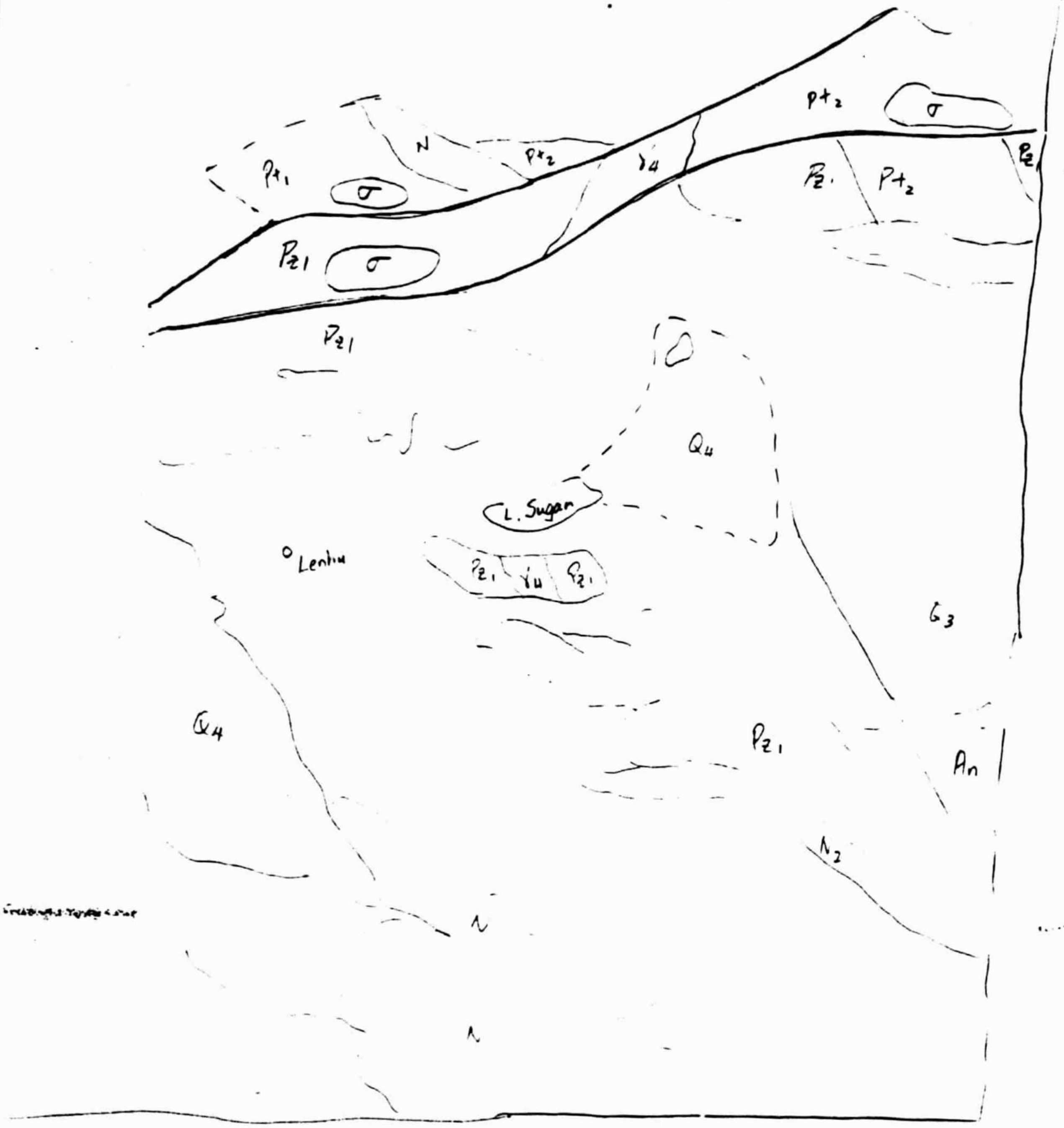

Fig 2.
(224)

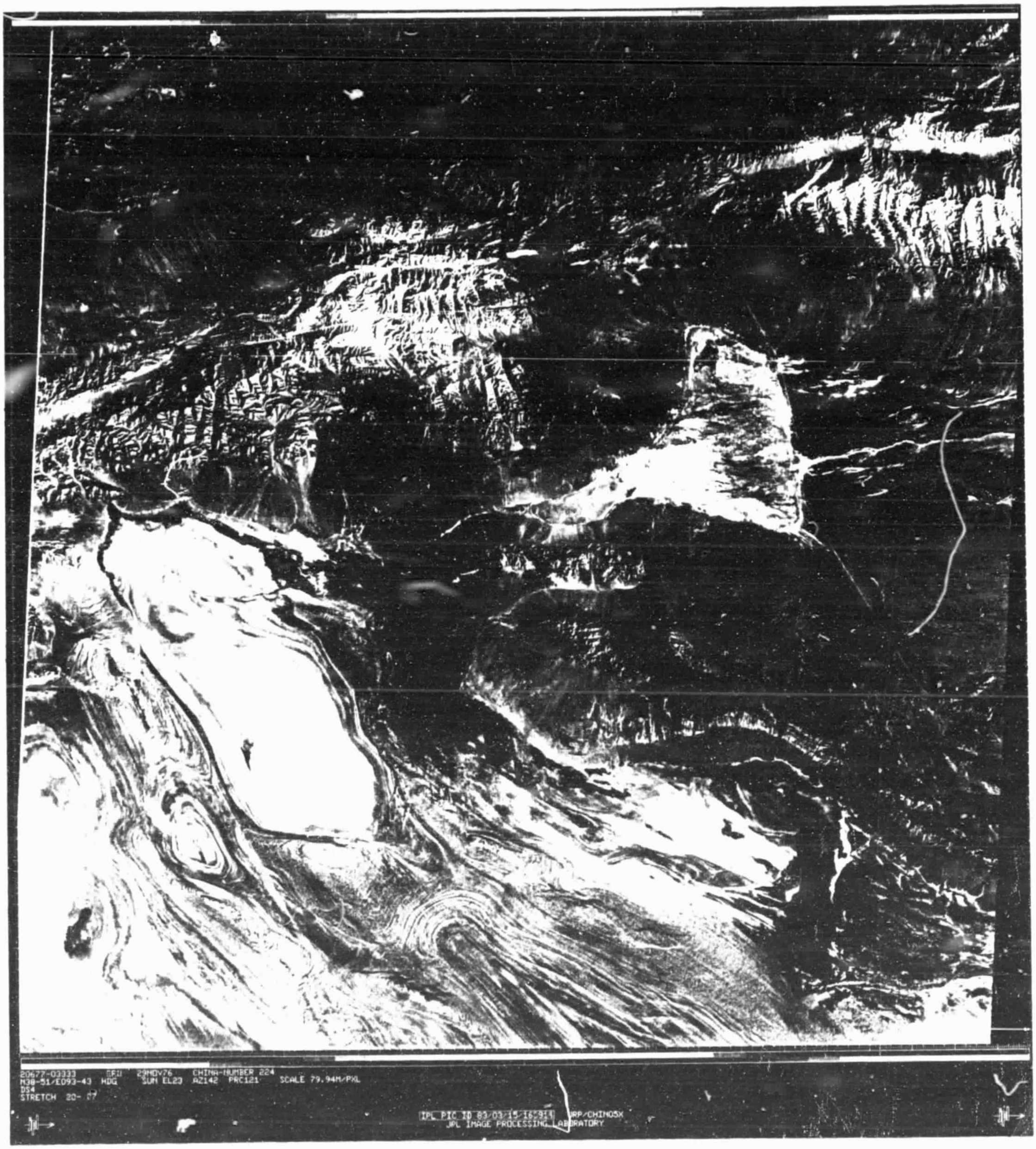
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Figure 3. (223 on the index map). Remarkable dragging of the strata can be seen here (as indicated by _._. lines). The sense of the dragging is consistent with the left-lateral displacement.

The Pz1 starata appear first on the northern side of the fault. It shows severe dragging. If this is correlatable with the Pz1 strata south of the fault in Figure 2, then the total left-lateral displacement of the fault amounts to about 250 km. Although there are strata marked as Pz1 on the Geology of China Map, which are identified in the LANDSAT image, the northern and southern units are evidently not continuous.

There are a number of other faults and faulted blocks in this frame. In particular, on the northern side of the fault, near the middle of the figure.

The southwestern corner of the frame where the Neogene strata appears marks the western termination of the Qaidam Basin.

figure 3

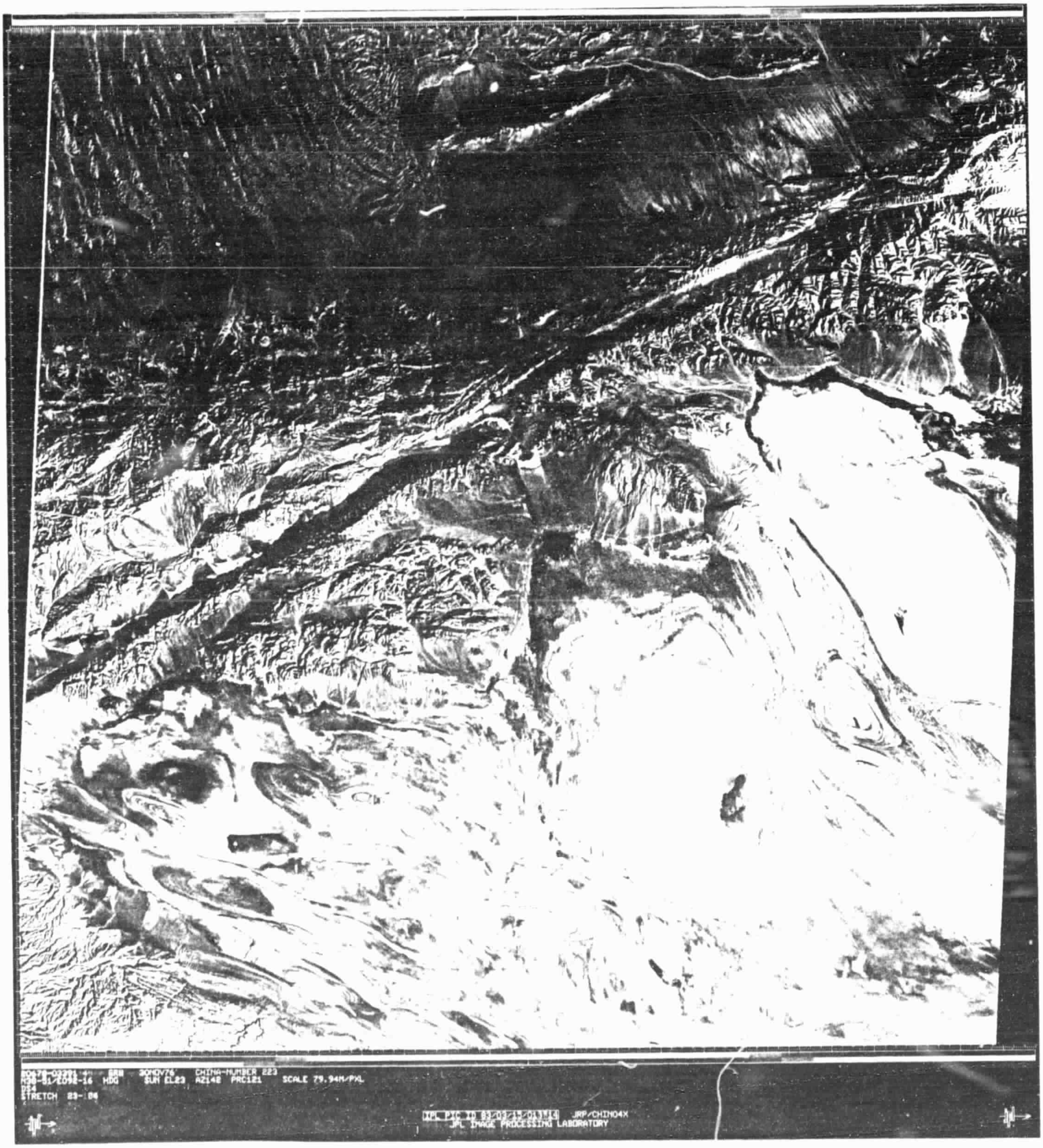
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Figure 4. (222 and 221) Faulting is becoming much more complex here than in Figure 3. The Altyn Tagh fault in the eastern portion of this figure is straddled by a granite body. Faulting seems to spread over a width of about seventy kilometers. Envidence to the north of the main fault is abundant. There are several rhomboidal basins created as a result of curvature in faults (2) and (3). The Altyn Tagh fault itself has a probably younger branch to the north of the granitic body; although it is clearly marked where it crosses the young alluvial features, the offset is not very large. Going further west this seems to be the branch that is linked to the main branch that is geomorphically very prominant. The southern branch (1') merges into the same fault but the not so clearly. Futher to the west (Fig. 4b), the fault gets into another prominant bend, in such a way that the left-lateral motion results in compression and hence the snow-capped mountains peaking at 5810 m.

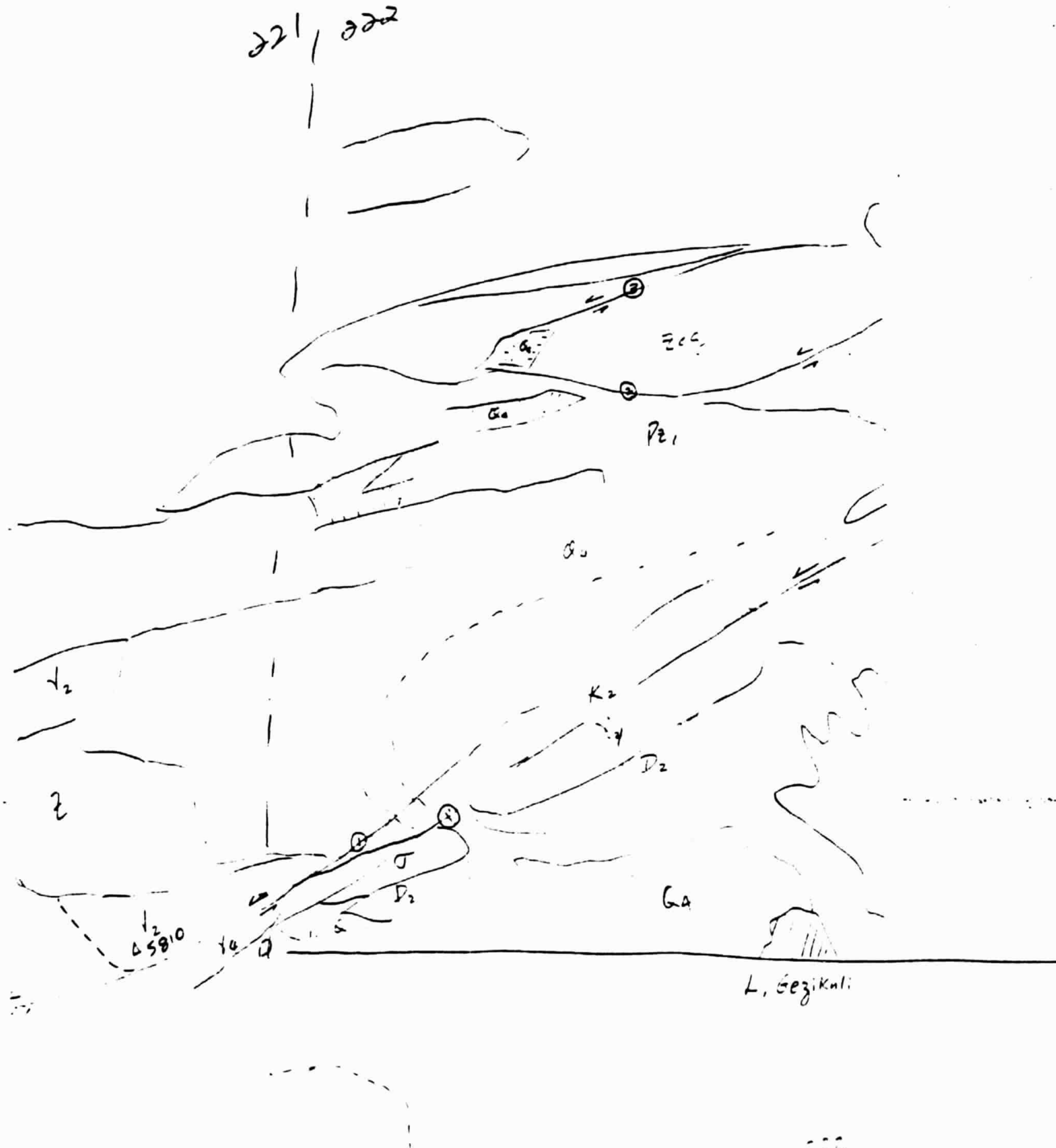
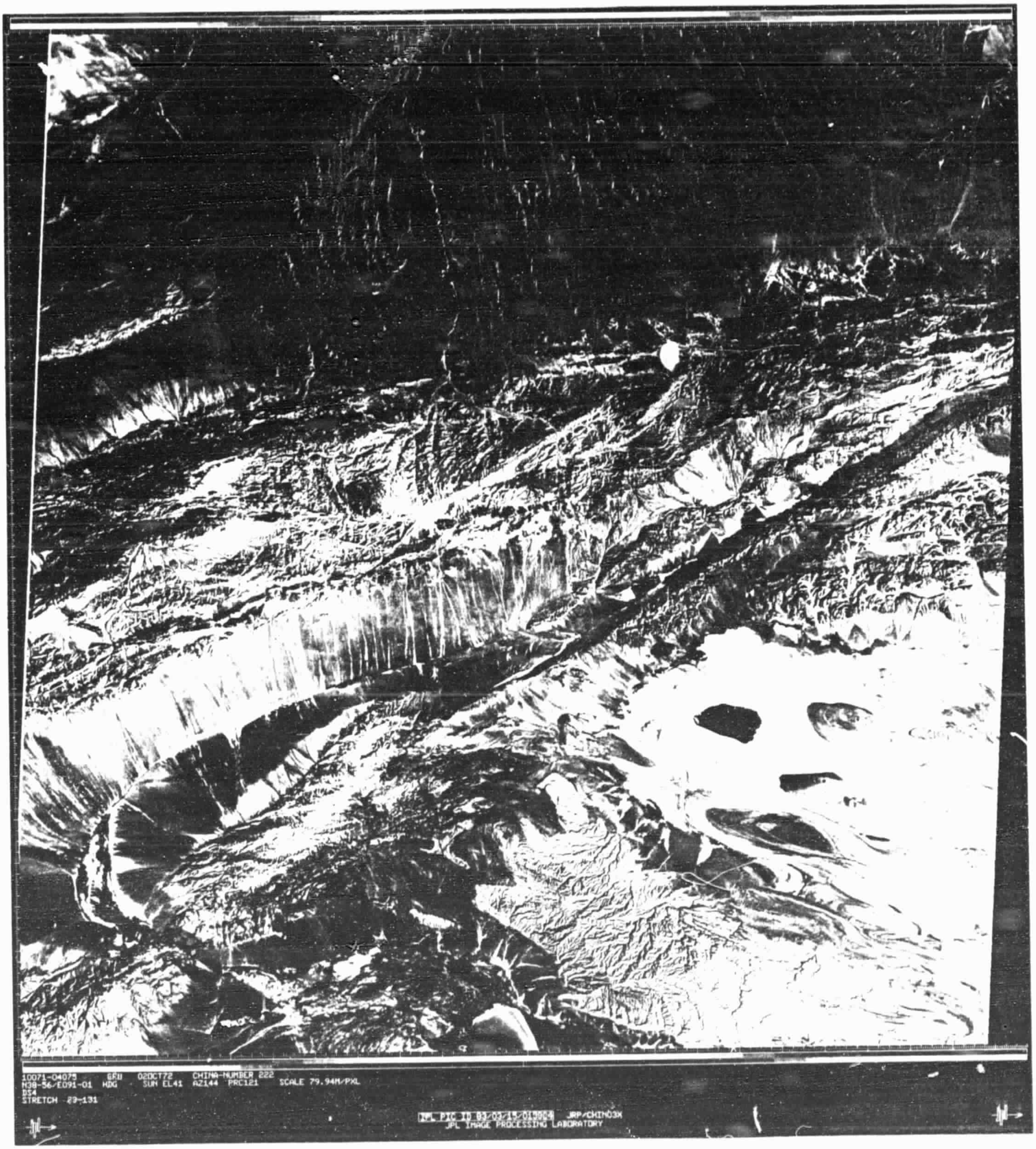


Fig 4a (222, 221)


10071-04075 GFU 02OCT72 CHINA-NUMBER 222
N38-56/E091-01 HDG SUN EL41 AZ144 PRC121 SCALE 79.94M/PXL
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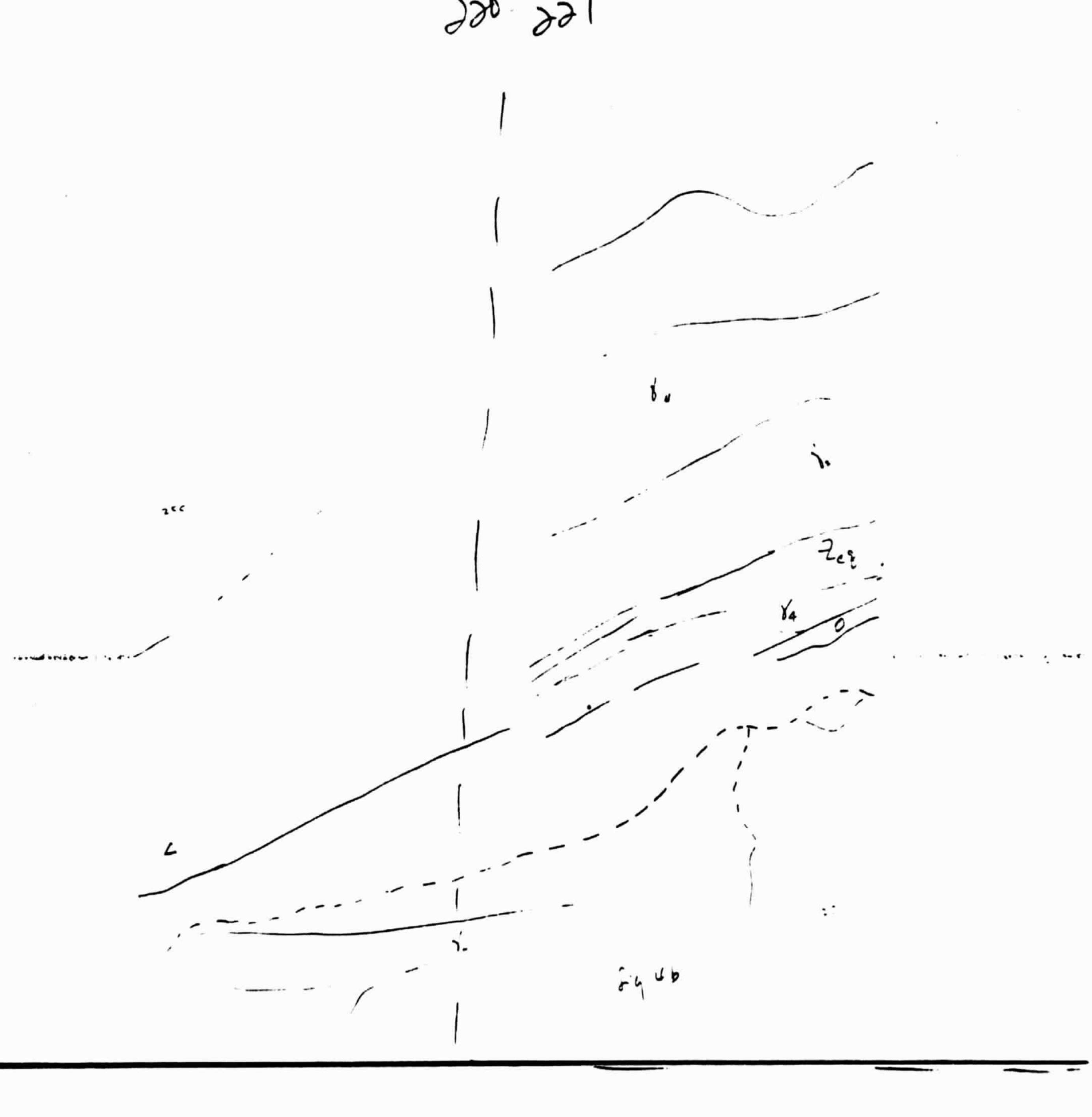

Fig 4b (220,221)


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JPL IMAGE PROCESSING LABORATORY

Figure 5. (255) There are clearly several branches of Altyn Tagh fault in this figure. The high peak along the fault at 6295 m is again associated with a bend in the fault and the rock on the northern side of the fault is granite and in the south Jurassic rocks. South of the fault there are a number of high mountains (the Mubayen Mtns, for example), and they are mostly associated with granitic intrusives.

It is interesting that the unit marked J1-2 is a Jurrasic unit that is clearly marked on the Geology Map and is very easy to distinguish on the LANDSAT image.

On the northern side of the fault in the Sinian strata there are a number of instrusive bodies and several ultra-basic bodies. These usually appear as mountains. The northern edge of this block is also a fault. See Fig. 6 for more discussions.

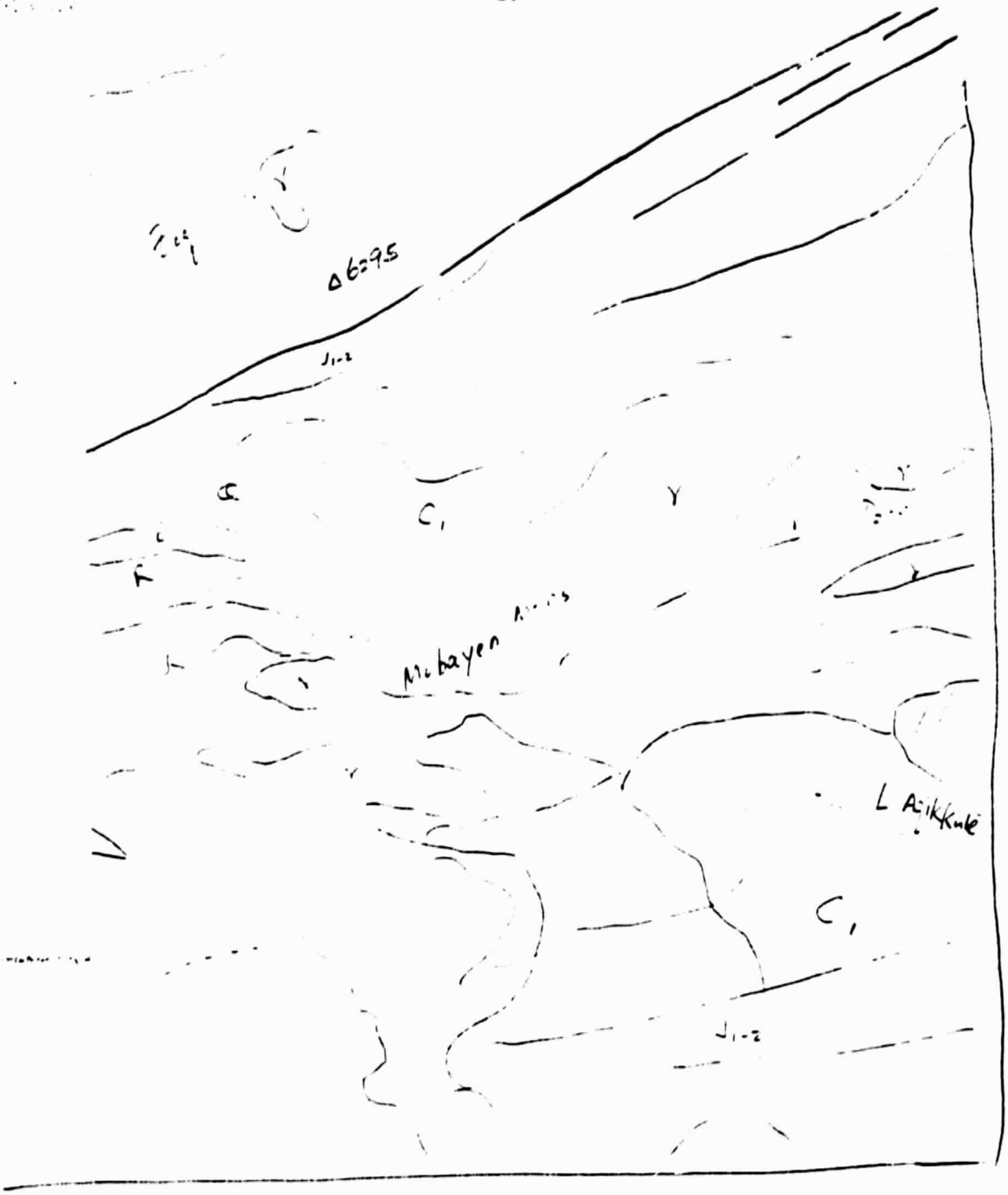

Fig5 (255)

255

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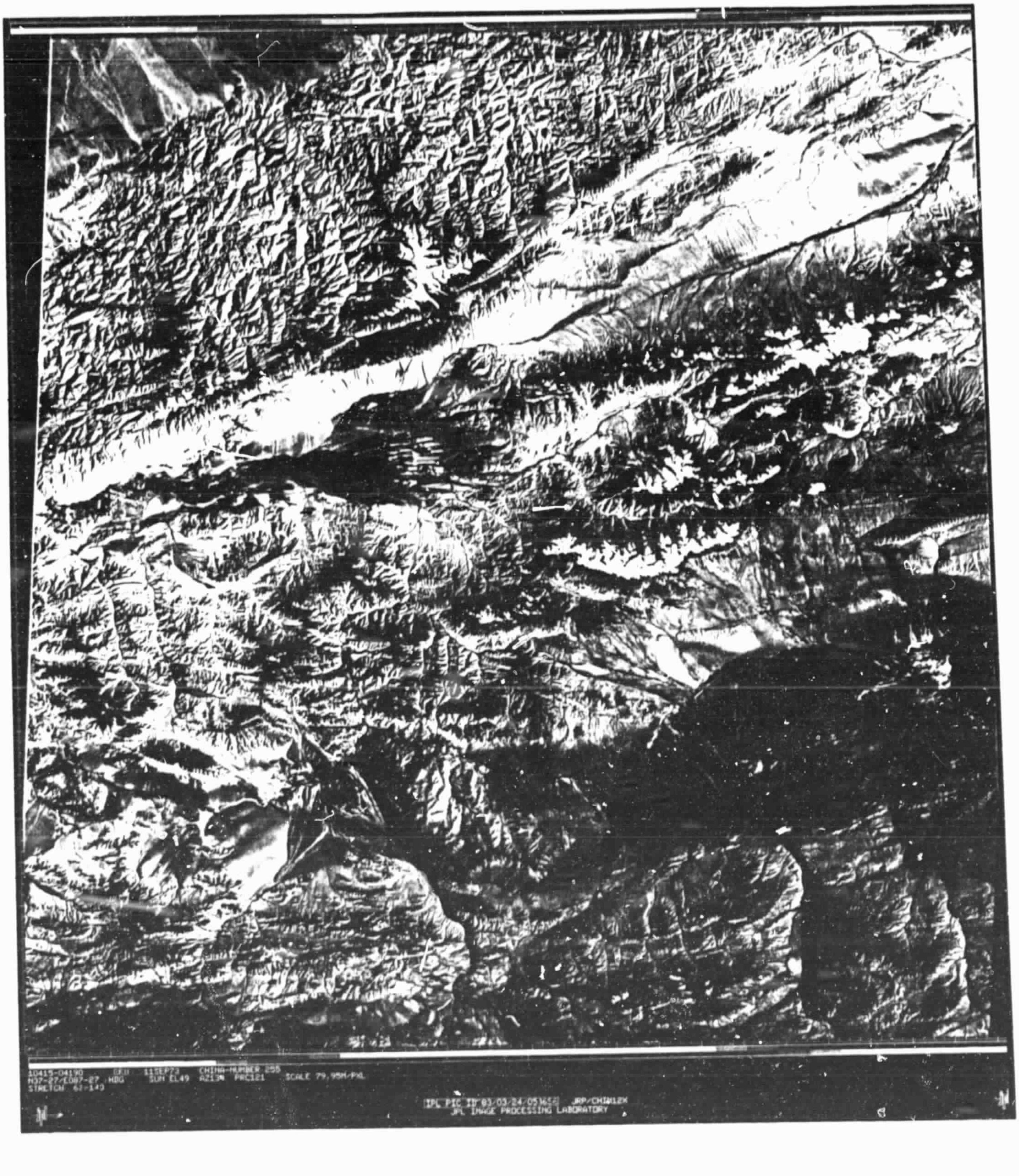

Figure 6. (254) This is the frame in which the recent nature of the left-lateral motion of the Altyn fault is made certain. As is clear in the lower left quadrant of the figure that several river have very noticeable offsets.

254

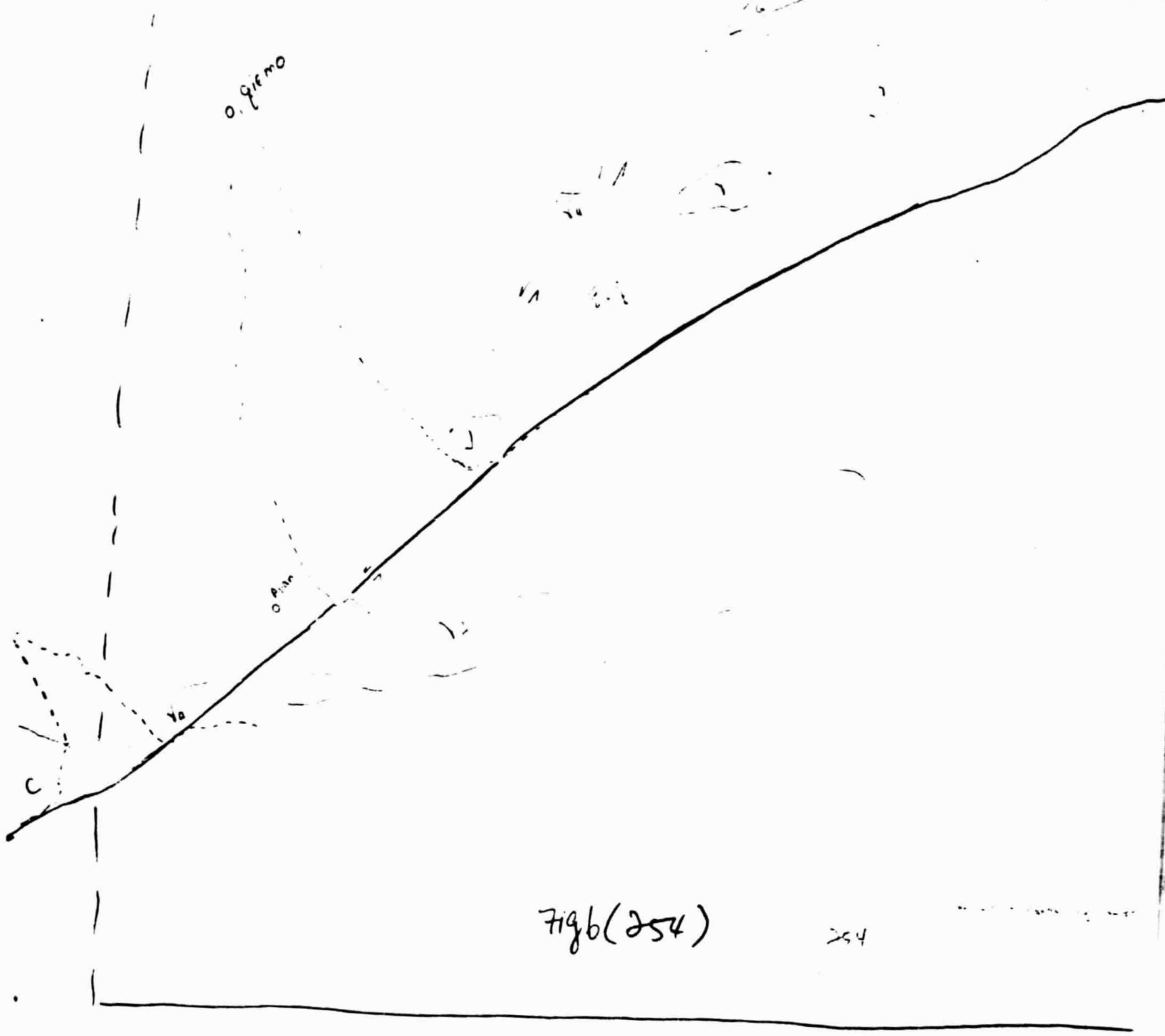

Fig 6(254)


1074-04253 05OCT72 ALTYN TAGH, CHINA
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STRETCH 54-132
JPL IMAGE PROCESSING LABORATORY

Figure 7. (253) In addition to the stream offsets across the Altyn Tagh fault, the interesting phenomenon is the presence of a major "asperity" in the fault. With the left-lateral motion along the fault, this asperity seems to have caused the opposite side of the fault to bulge up and also leaves behind it a rhomboidal basin. It can be surmised that the whole length of the ridge on the north side of the fault was created as the asperity moved northeastward.

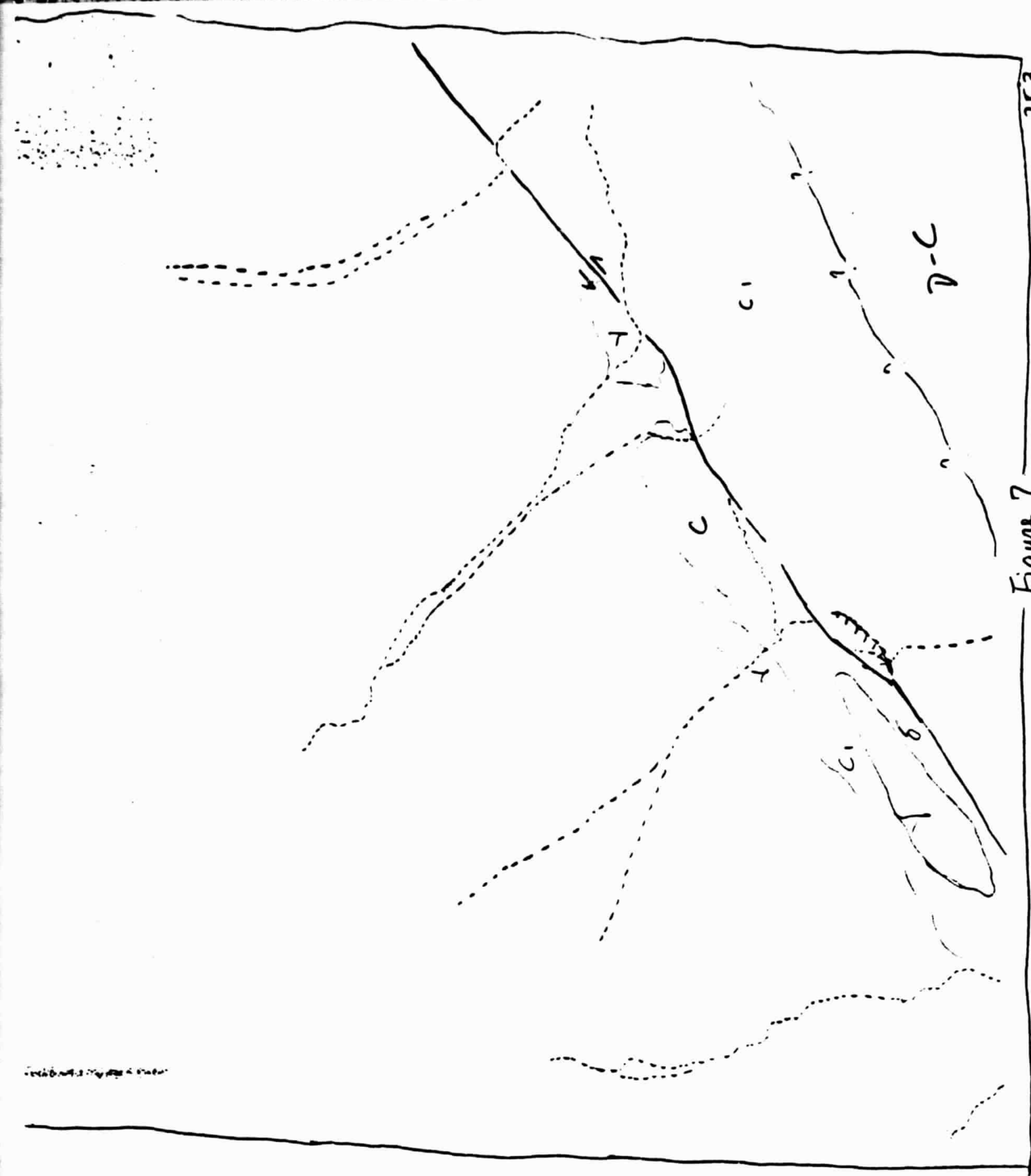
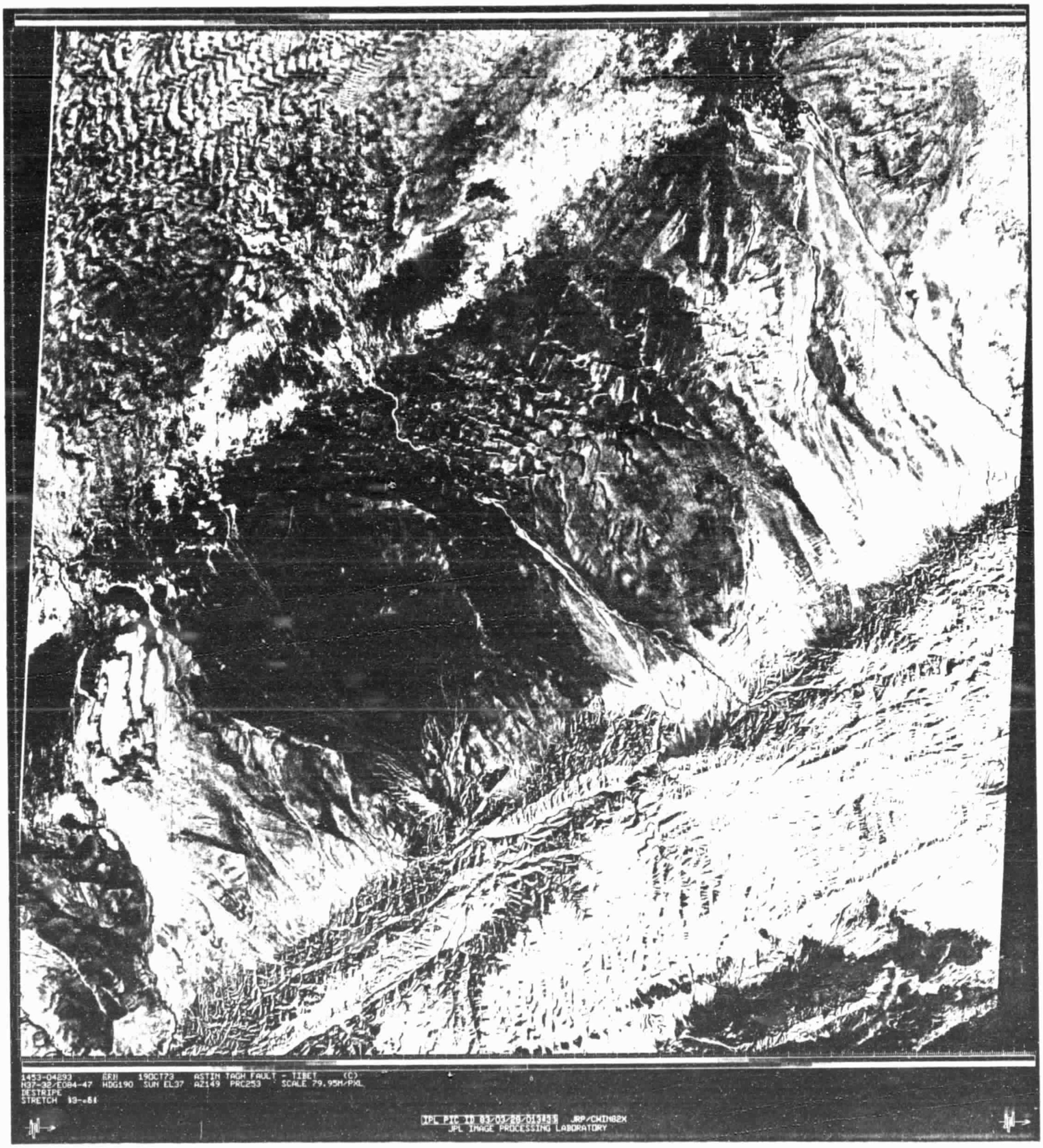


Figure 7
(253)


1453-04293 GRN 19OCT73 ASTIN TAGH FAULT - TIBET (C)
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DESTRIPE
STRETCH 19-.81
IPL PIC ID 83/03/28/013433 JRP/CHIN82X
JPL IMAGE PROCESSING LABORATORY

Figure 8. (284) Here the Altyn Tagh fault has broken into two main branches, one following a northeast-southwest trend and the other a nearly east-west trend. The former branches further going southwest; here an extension basin was formed. As a result of this extension, wide-spread basaltic flows and volcanoes are found here. This is one of the few places in Tibet where recent volcanism has taken place.

The northern branch is at the mountain-desert (Tarim) edge. There evidence of recent left-lateral displacement is still abundant.

The Carboniferous strata on the eastern side of the NE-SW trending branch seems to be very pliable; dragging is evident (indicated again by the _._._._. lines.)

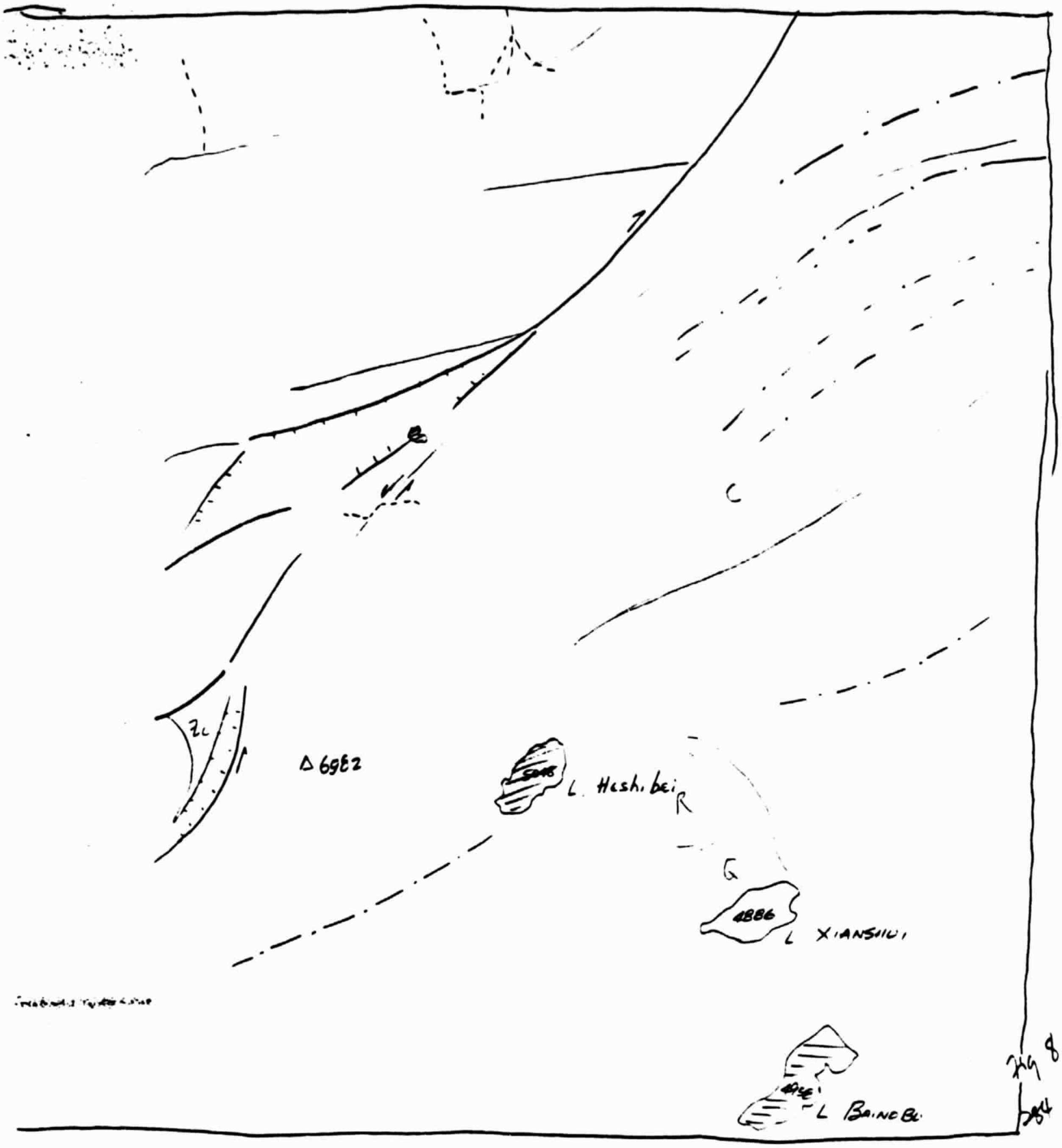

Fig. 8 (284)

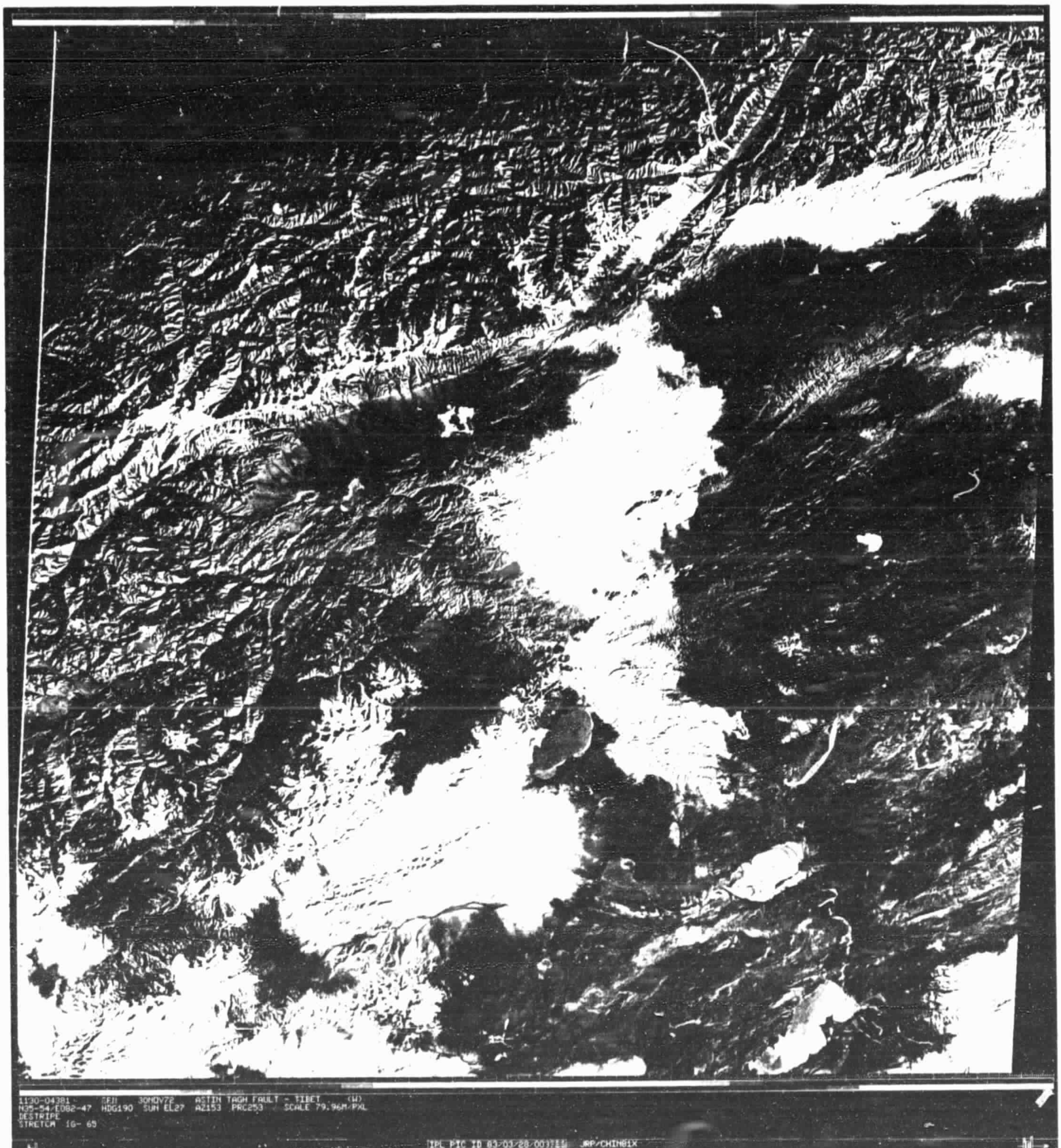
1130-04381 SFJI 30NOV72 ASTIN TAGH FAULT - TIBET (W)
N35-54/E082-47 HDG190 SUN EL27 AZ153 PRC253 SCALE 79.96M/PXL
DESTRIPE
STRETCH 16- 65
IPL PIC ID 83/03/28/003715 JRP/CHIN81X
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Figure 9. (283) The southeastern corner of the figure shows the extensive basaltic volcanic field. The SW trending continues to the southern edge of this figure. The Northern branch enters from the northeast corner of the figure and shows many left-laterally offset channels as indicated by the dashed lines. Starting from the middle of the figure however, there is a marked change of trend; further west, the fault is WNW-ESE trending. The fault scarps become steeper and the movement is dominated by thrust faulting. The mountains are also much higher; near the lower edge of the figure, a peak stands at 6903.

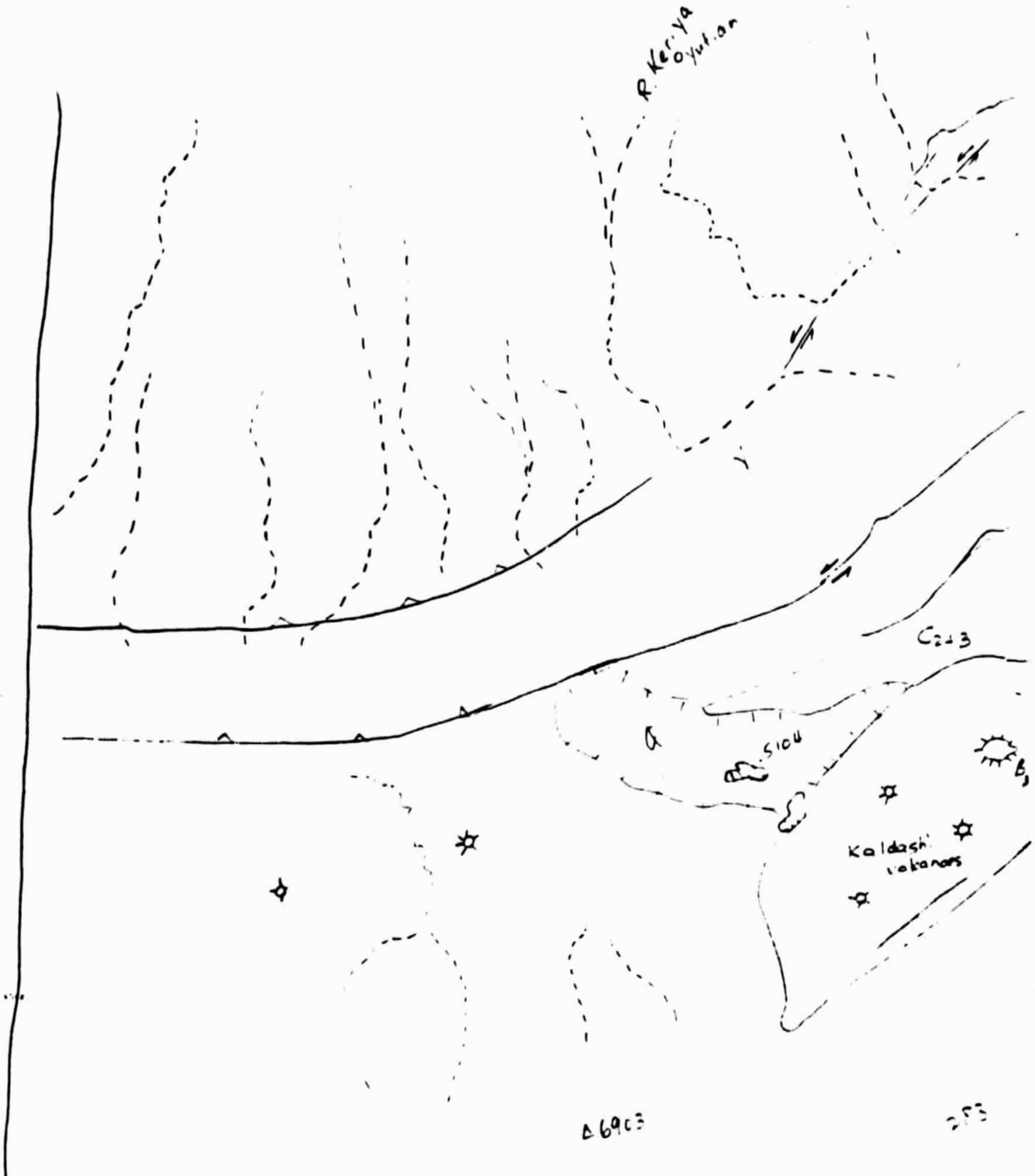

Fig. 9

(283)

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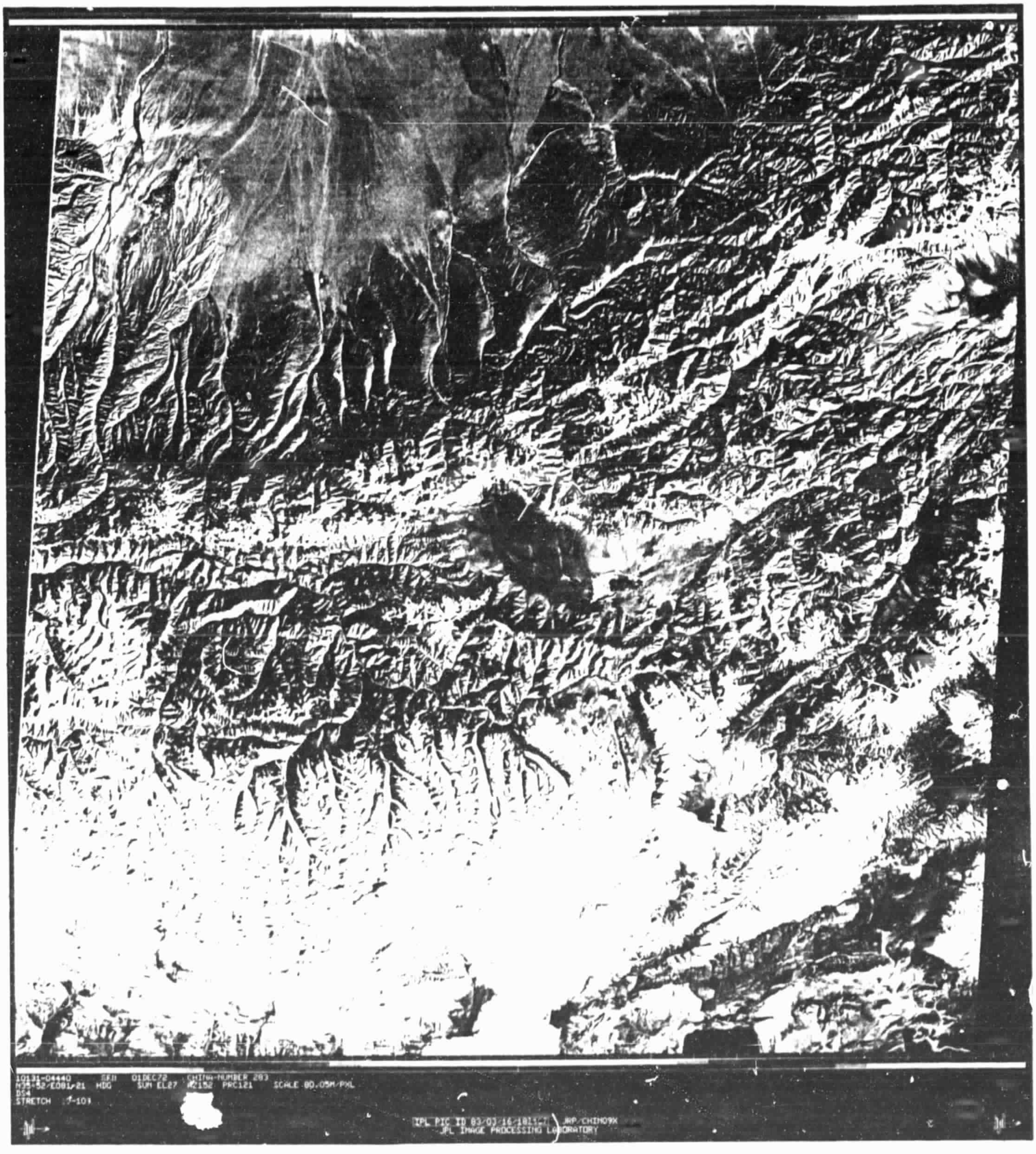


Figure 10. (250) Here we see the fault at the juncture between the Tarim and the Tibetan Plateau. Toward the lower left, an impressive closed fold system is seen. The core of this fold is composed of Paleozoic rocks the flanks are however Cretaceous and younger rocks. Several branches of the thrust faults are clearly displayed. No left-lateral motion along the faults can be discerned.

Along the WNW trending section the compression is probably the strongest as the direction is almost perpendicular to the direction of impingement of Indian Plate. As a matter of fact the compression is so strong that further to the north in the middle of the Tarim desert the basement rocks have been folded and probably faulted to poke through the sand; these structures have the same trend as the faults shown in this figure. Along the northern edge of the Tarim Basin are the Kepin mountains, where impressive fold structures are seen.

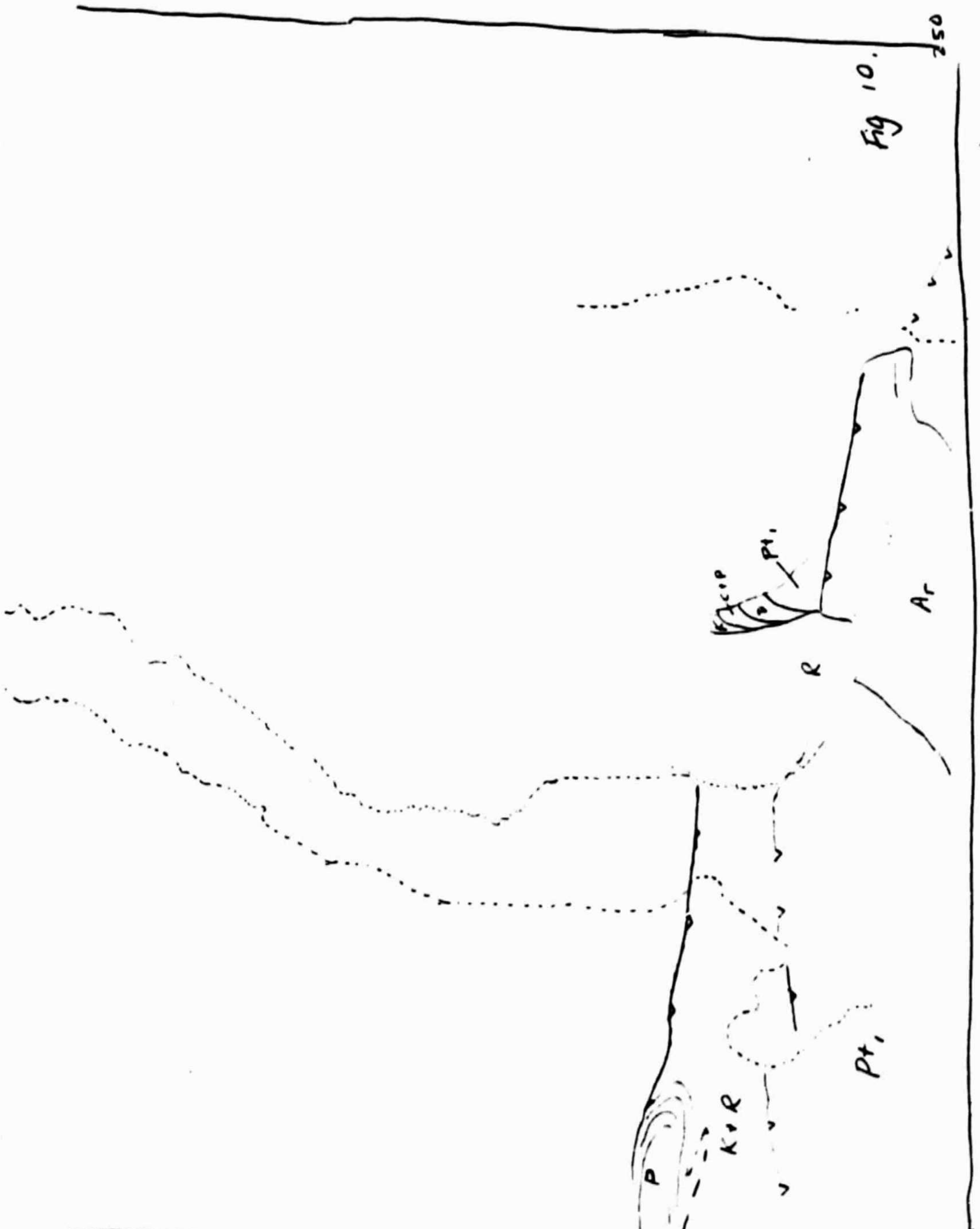
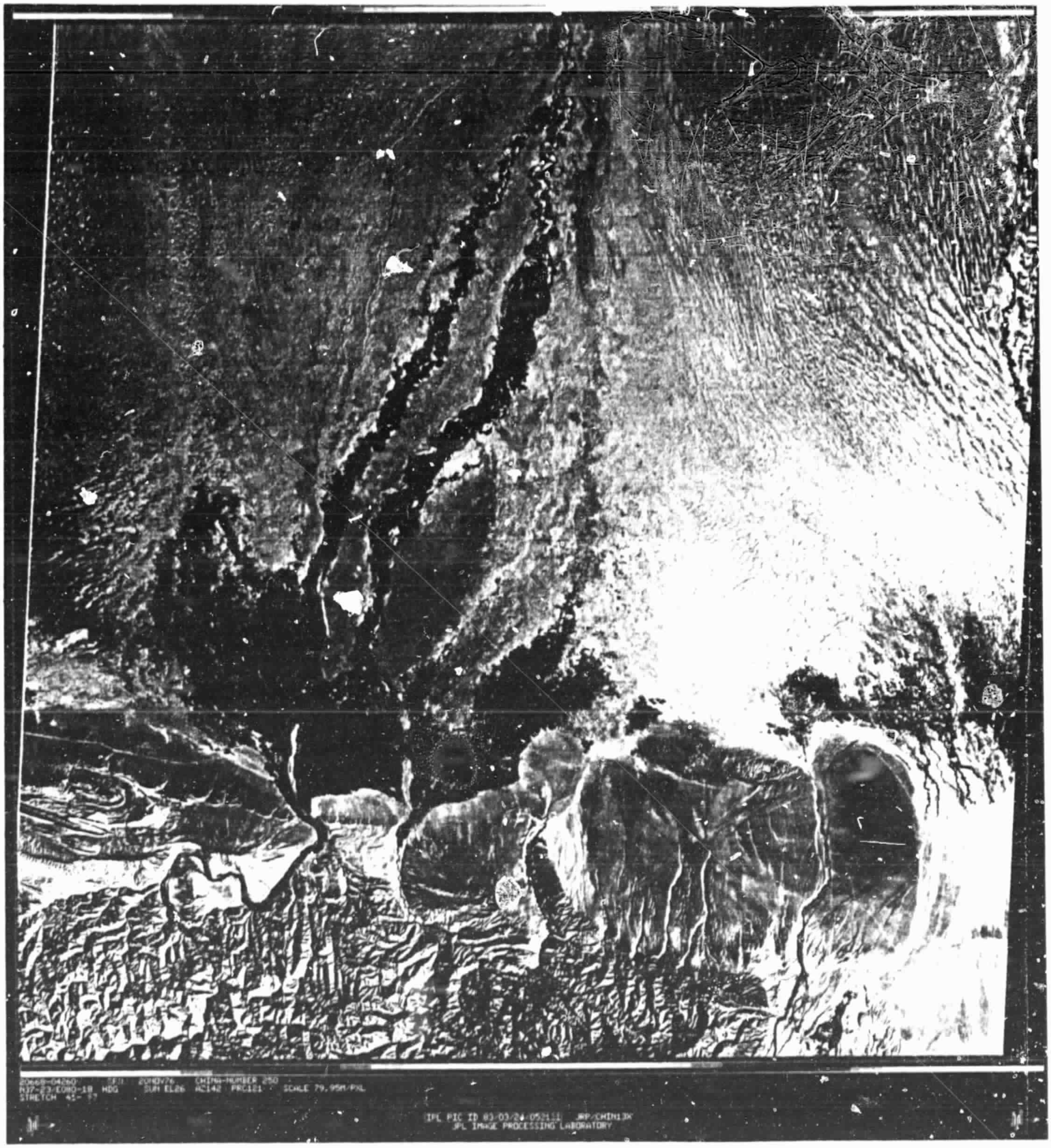


Fig 10 (250)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N37-23/E080-18 HDG SUN EL26 AZ142 PRC121 SCALE 79.95M/PXL
STRETCH 41- 77
IPL PIC ID 83/03/24/052111 JRP/CHIN13X
JPL IMAGE PROCESSING LABORATORY

Figure 11. (248) In this frame we can again see the thrusting of the Tarim near the edge of the dessert. The foothills are underlain by Neogene to Quarternary sedimentary rocks. Because of its proximity to the dessert, the area is covered by eolian deposits and thus have very smooth topography. However, the downward slopes have been cut by many WNW trending faults. Here some of the stream offsets are created probably not by the lateral movements of the faults but by the barriers they form in front of the streams. The fact that these faults show clearly through areas that are subjected to rapid eolian deposition implies that the tectonic process is extremely active. The deeply dissected valleys and very high altitudes the mountains attain in the northern part of the Tibetan Plateau is a part of the same process.

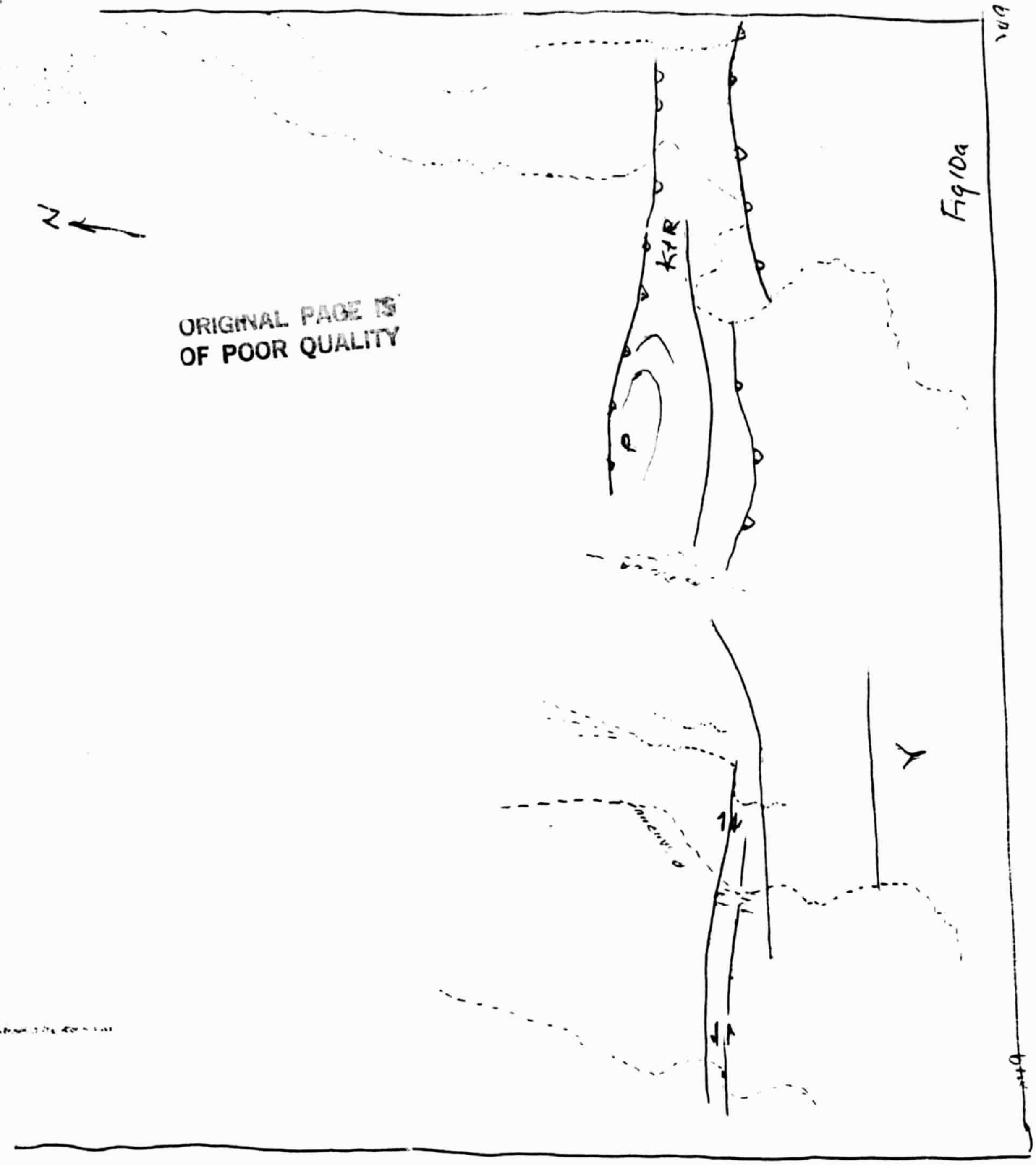

Fig 10a

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Figure 12. (247) Continuation of the last frame to the west. The mountain chain makes a dramatic turn to the northwest. The most interesting observation in this frame is that faults striking in NWN directions have right-lateral stream offsets across them. Thus we have cross from dominantly left-laterally strike-slip faulting in the eastern section of the Altyn Tagh fault, to areas where thrust faulting is the dominant mode of deformation and here, in between the Tibetan Plateau to the east and the Pamirs to the west, compressional structures and NWN striking strike-slip faults are found to coexist.

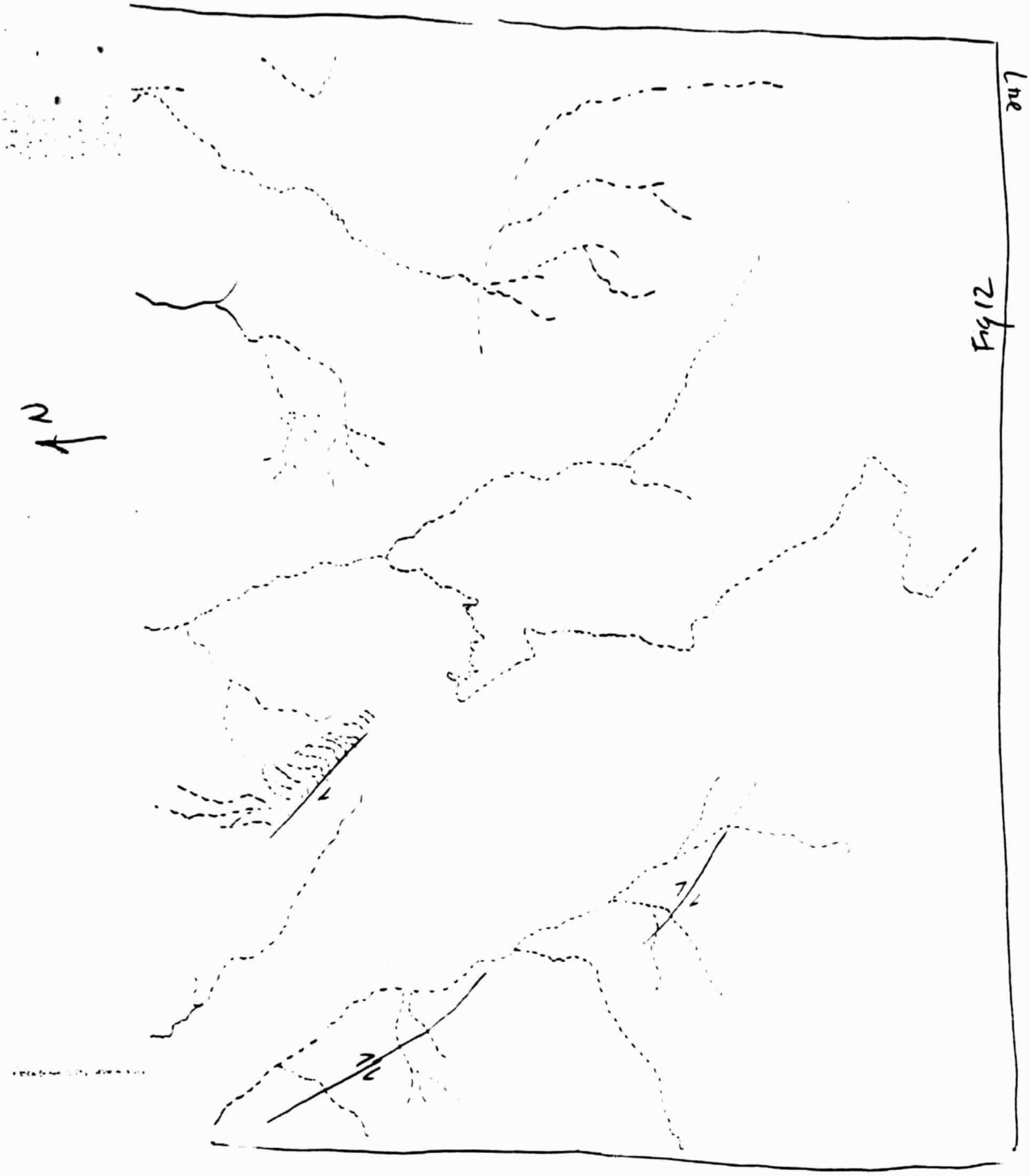

Fig 12 (247)

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