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EVALUATION OF EREP TECHNIQUES FOR GEOLOGICAL MAPPING

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FOREWORD

This document is the final report on the Investigation of Skylab Erep data, submitted in accordance with the requirements of Ehibit "A", Statement of Work, NASA Headquarters Proposal Regristration No. 9639.

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PREFACE

This report is submitted as part of the requirement for M.Sc. degree in Photo-geology and Remote Sensing (ITC) at the International Institute for Aerial Survey and Earth Sciences (ITC), Enschede, The Netherlands.

Enschede, January 1975.

A B S T R A C T

Multispectral photographic imagery from experiment S190A of Skylab-3 mission, covering part of the southern Pyrenees and Ebro basin in Spain, have been studied for their utility in geological mapping. Three subframes around Jaca, Pamplona and Calahorra, respectively were selected for detailed study. Photo-interpreted geological maps of these areas (on 1 : 270.000 scale) were prepared after acquiring necessary ground truth data by field observations. A comparison of these maps with existing similar scale as well as smaller scale maps indicates that the imagery is good for reconnaissance geological mapping of less known areas. The skylab imagery is no exception to the inherent limitations of aerial photograph while interpreting complex areas.
A relatively short time required for covering large areas, better delineation of structural features including geofractures and megalineaments, and providing good regional co-ordination in geological mapping, are some of the definite advantages of synoptic space photography over the conventional means.
The future research and development should aim at acquiring adequate stereoscopic coverage of areas and still better resolution for full exploitation of the potentials of space photography.

ACKNOWLEDGEMENTS

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EVALUATION OF SKYLAB S190A MULTISPECTRAL PHOTOGRAPHIC IMAGERY FOR GEOLOGICAL MAPPING.

1. INTRODUCTION

Skylab mission is another step forward in the direction of acquiring knowledge of earth's resources from satellite-borne remote sensors. For gathering data, an orbiting manned workshop - Skylab, was established and maintained in the space between May 1973 and February 1974, at an orbiting altitude of 234 nautical miles above the earth. The series of Skylab missions began with the launching of Skylab-1 unmanned Saturn Workshop (SWS). Subsequently a manned Command & Service Module (CSM) Skylab-2 was launched to dock with SWS. After succesful completion of Skylab-2 mission, which lasted 28 days, two manned revisit missions Skylab-3 & Skylab-4 missions were taken up each scheduled for 56 days duration. The crew of Skylab missions performed a number of scientific and technological experiments during this period.

The imagery used for the present evaluation study were obtained from SL-3 Skylab mission which was launched on 25th July 1973 and remained in orbit for 59 days. Under the Earth's Resources Experiment Package Programme (EREP), experiment No. S190A, multispectral photography in six channels was carried out over selected areas. Two sets of photographs covering part of northern Spain and France were taken-up for interpretation and evaluation of their capabilities for the purpose of geological mapping.

1.1. Objective

The objective of present investigation is to assess the utility of Skylab pictures for the purpose of geological mapping.

1.2. Scope

The scope of this work includes an overall interpretation of Spanish part of the area covered by the Skylab photographs, and a detailed interpretation and reconnaissance of three subframe areas selected for the purpose of evaluation studies. An objective assessment of interpretation technique has also been attempted.

2. PROCEDURE

The analysis and interpretation of data from Skylab S190A photographs has been carried out in a number of phases. A sequential description of different stages involved follows in the following paragraphs.

2.1. Preparatory stage

In the preparatory stage the data was acquired (from NASA) in form of diapositives of multispectral photography in six different bands (details in table I). To suit the requirements of interpretation work a two and half times enlargement print of black and white negative (9" x 9") was prepared. The extent of the area covered by the format was located on the map by comparing ground details on existing maps. (Plate I, location map). An inventory was prepared for collecting external information available. This was procured in form of small scale geological maps and publications on the relevant areas. A detailed plan was chalked out for carrying out the investigation. It involved formulating the procedure and attaining a state of readiness for taking-up the job.

2.2. Visual Interpretation

A quick analysis followed by a detailed visual interpretation was carried out during this phase. The standard photo-geological interpretation technique was employed with judicious application of external information at different stages of discrimination and identification.

The interpretation results have been compiled in form of a preliminary geological map on 1:270,000 scale. This map with adequate drainage lines and other ground details forms the base map for further work.

Subframes were selected at this stage for further detailed analysis and acquiring ground truth in these limited areas by field checking.

Diapositives of different bands were studied on a light table with the help of a magnifying lens and also by projecting areas of interest on a suitable scale (1:270,000) over a screen. The additional information thus obtained was incorporated in the geological maps of subframe areas. Terrain accessibility maps for each subframe areas were also prepared by enlarging existing road maps and a working programme for field checking was outlined. Transparent overlays of the geological maps were made to fit the corresponding terrain accessibility maps for using them during the fieldwork which lateron were found to be quite advantageous.

2.3. Ground truth acquisition

This phase was carried out in two stages:

a) Existing geological maps and literature about the area were consulted with a view to familiarising with the geological set up of the area in general, and collecting detailed information of subframe areas in particular.

b) Regional geological traverses were taken to examine different rock outcrops with more detailed field observations in the subframe areas.

2.4. Adjustment of the interpretation

This phase includes:

a) Detailed re-interpretation of the subframe areas in light of the ground truth data. A critical review of the results and supplementing additional information was possible by superimposing images of different bands on the map over a screen with the help of a projector.

b) Preparation of geological maps and cross-sections through the areas.

2.5. Evaluation

In the final phase of work an assessment of the capabilities of the Skylab imagery was made.

2.6. Time Involved

The time required for this type of investigation largely depends on the availability of ground truth data both in form of acquiring available information and the facility for carrying out fieldwork. A time break up of the present investigation which includes interpretation of 3 subframe areas having 3,400, 2,700 & 2,600 square kilometers of area respectively, on 1 : 270,000 scale, for a full time qualified interpretor and a part time co-ordinator/guide, may help in forming an idea about the time requirement.

Phase	1.	Preparatory	60 man hours
"	2.	Visual interpretation	120 "
"	3.	Groundtruth acquisition	60 "
"	4.	Adjustment of interpretation	90 "
"	5.	Evaluation	90 "
		t o t a l	420 man hours

3. DATA CHARACTERISTICS

The data for the present investigation have been provided by the Multispectral Photographic Camera (MPC) under experiment No. S190A of the Earth's Resources Experiment Package Programme (EREP) of SL-3 mission. The objective of the multispectral photography is to provide an accurate analog record of the scene radiance and a base for wide range of user-oriented studies. Multispectral photography was carried out in six channel bands using different types of films and filter combinations to meet the spectral band and pass requirements of each camera station. The description of film type and filters used is given in the following table.

TABLE I. S190A Film types

Camera station No.	S190A film	Spectral band μm	Standard filter	Duplicate film
1.	1R Aerographic B & W, type EK 2424	0.7 to 0.8	CC	2420
2.	ditto	0.8 to 0.9	DD	2420
3.	Aerochrome 1R colour, type EK 2443	0.5 to 0.88	EE	SO-360
4.	Aerial colour (high resolution), type SO-356	0.4 to 0.7	FF	SO-360
5.	Pan-X aerial B & W, type SO-022	0.6 to 0.7	BB	2430
6.	ditto	0.5 to 0.6	AA	2430

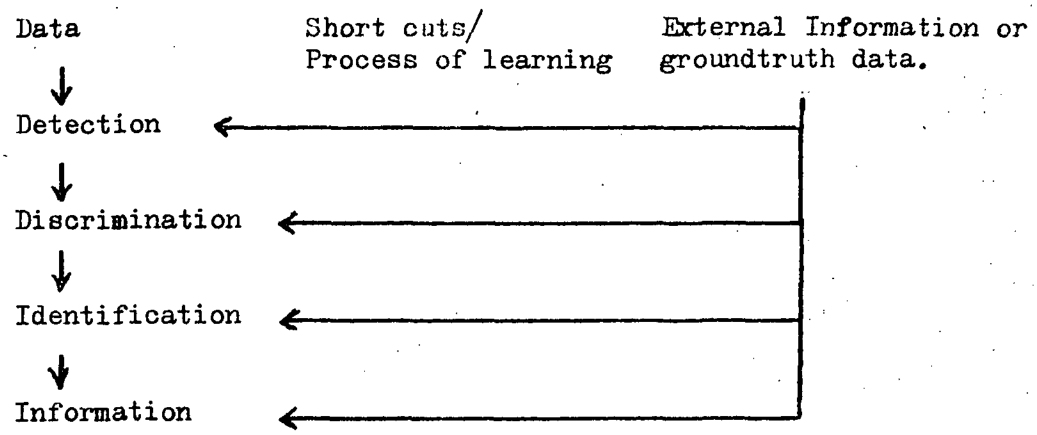
The original film having a format size of 2.5 inch square and covering about 25,600 square kilometers of area, were preserved and duplicate films were made for using them in interpretative analysis and experiments. The data address of the material which has been made available for the present investigation is given below:

Mission	SL 3	
EREP Experiment No.	S190A	
Roll No.	33 - 07702	
Frame Nos.	318 and 319	
Orbit No.	32	
Flight Date	9/11/1973	(11th September 1973)

The two frames of photographs in all six channels were four times enlarged to 9 inch square format and diapositives of the same were provided for the investigation. The diapositives include one colour, one false colour, two infra-red (black and white) and two black and white. To provide a base for the interpretation study a two and half times enlargement of black and white print was made from the negative of camera station 5 (B & W band 0.6 to 0.7 μm).

4. TECHNIQUE OF VISUAL INTERPRETATION

The technique which has been employed for the interpretation of the Skylab pictures is essentially the same as used for standard aerial photo-interpretation work. In essence the technique uses basic cognizant factors like tone, texture, shape orientation, colour etc. of the picture elements and their mutual relationship so as to evolve a pattern which could be identified to some useful information. The following flow-sheet depicts the whole process of visual interpretation technique.



The process of Detection is the first interaction of the photo-element on the eye. The resolution property of the data, however, puts a contraint for the objects below resolution limits. 'Contrast detection' - due to contrast or acutance of adjacent data elements and 'Boundary detection' - due to the physical configuration of data element in relation to its surroundings, are the types of detection generally observed.

Discrimination is the process of categorising similar objects to form a recognisable pattern which may be identified in three different ways to reach to the level of useful information:

a) by spontaneous recognition, whereby a trained photo-interpreter compares the pattern with various combinations of photo and geomorphic elements of known objects through his knowledge and previous experience, b) by logical inferences - it is possible to reach to a logically sound inference through inductive and deductive reasoning, which may lead to identification of the pattern and c) by ground truth acquisition, which includes gathering information from available geological maps and literature and by actual field observations of rock outcrops.

There are short cuts available in the whole process of interpretation of data into information, at various levels of detection, discrimination and identifcation with the help of external information. In actual practice the interpreter keeps on utilizing external information at every stage he feels necessary. The emphasis between the interpretation and external information is shifted according to the need and interpreter's ability to synthesise the two and at this stage the process of learning and interpretation go pari pasu.

A growing tendency advocated by some workers, for an unbiased interpretation has been noticed in some recent literature. The proposition seems unrealistic as an unbiased interpretation does not take cognisance of very important tool of external information. For a realistic interpretation it is essential that the use of external information is made to the optimum degree.

5. INTERPRETATION

5.1. Introduction

The two photographs used for the present study cover a total area of 48,000 square kilometers having a common overlap of about 4,000 square kilometers. The area mainly falls in the north-eastern part of Spain except 15,000 square kilometers in the upper half of the photographs No. 319 which lies in the French territory (location map plate no. 1). Present study has been restricted to the area in Spain which comprises southern Pyrenees mountains and part of Ebro basin around Soria, Logroño, Pamplona and Huesca towns.

For detailed evaluation studies, 3 subframes were selected around Jaca, Pamplona and Calahorra respectively. These areas have more lithological units, better structural features and relatively simple geology. Availability of geological maps and literature and better terrain accessibility have also been the criteria for selecting these areas.

5.2. Resolution and Quality of Skylab Imagery

Experiments for image evaluation analysis of various Skylab missions were designed and performed by NASA (EREP Sensor performance Report). Test sites were selected from each mission and the data were checked for determining Spatial Resolution, Film-Reseau Conformity and Image Registration. The spatial resolution determination was carried out by Visual Edge Matching (VEM) and Visual Image Evaluation (VIE) techniques. The following tables summarise resolution values and corresponding Ground Resolution Distances (GRD) obtained from VEM & VIE analysis. VEM analysis was performed on SL2, SL3 & SL4 imagery, while VIE analysis was carried out on SL2 imagery only. However, no major resolution changes were observed. It may be noted that the resolution from 190A camera was, in general, about 10% higher than the predicted values.

TABLE II. Image quality results, line per mm (lp/mm original negative)

Station	Predicted Res. 1:6:1 contrast	Observed (VEM) 1:6:1 Std.Dev.	PI Res. (VIE) (3:1)
1	28	29 ± 4	60
2	25	25 ± 3	65
3	26	—	55
4	70	—	110
5	67	75 ± 9	95
6	53	63 ± 9	85

TABLE III. Ground Resolution Distances, S190A (O.N.) at medium contrast *)

Station		GRD (feet)
1.	O.N.	176
	Dup	210
2.	O.N.	195
	Dup	230
3.	O.N.	170
	Dup	200
4.	O.N.	85
	Dup	120
5.	O.N.	90
	Dup	100
6.	O.N.	95
	Dup	100

*) VIE analysis at 3:1 contrast is used for the colour channels. The caliberated VRE medium contrast is used for the black and white channels.

5.3. Images used for Present Study

5.3.1. Quality

The two sets of imagery used for the present study (SL-3, frames 318 & 319) have their principal points at Lat. N 42°00', Long. W 2°00' and Lat. N 43°00", Long. 0°00' respectively. The quality of the photographs and diapositives is good having almost no cloud cover (except a few specks at the snowy peaks). Electrostatic markings are occasionally seen on black and white print.

5.3.2. Stereoscopy

The two photographs have about 10% forward overlap which helps viewing a thin strip of the area, on a reduced level of stereoscopic vision. It has been realized, beyond any doubt, that the 3-D viewing has definite advantages over the monoscopic vision to which most of the area has been subjected during the interpretation. Flat fusion with the help of black and white diapositives of different bands was tried for delineating drainage lines and deciphering major structural trends, with a moderate success.

5.4. Description of Rocks Stratigraphic Units

In the following sections a general geological set-up of the area is briefly described giving photo-characteristics of different rock units and a scheme of classifying them in order to facilitate a discussion about their interpretability in subframe areas.

There are 12 rock-stratigraphic units present in the area. They have been identified on the basis of their photo-characters and ground truth data. The description of individual units is as follows:

1. Granite: Characterized by high relief, rounded topography, dendritic drainage pattern, no cultivation, low vegetation, light to medium grey tones in black and white and bluish grey to white tones in colour photographs.

2. Palaeozoics: (Undifferentiated) consist of dark grey slate, grey limestone and greywackes, characterized by relatively low relief, occasional cultivation, fairly good vegetation, incepient linear bedding structures, dendritic to semi-controlled drainage pattern, medium to dark grey tones in black and white and bluish green in colour photographs.

3. Red beds: Reddish-brown siltstones, shale and sandstone characterized by moderate relief, dense dendritic drainage pattern, no vegetation cover and medium to dark grey tone. The unit is not easily differentiable in black and white photograph but clearly marked by reddish brown colour in the colour photograph.

4. Brown limestone: Consists of alternating sequence of brown marls, marly limestone, and brownish grey limestone. Characterized by linear ridges, resistance to erosion, dip slopes often well marked, association with the 'white limestone', fairly vegetated, medium grey tones and bluish green with brown tints in colour photograph.

5. White limestone: Consists of dolomite, thick bedded white to greyish white limestone and grey weathering limestone at the top. Characterized by moderate relief with resistant ridges showing good dip slopes. Sparsely vegetated light grey to white tones in both black and white, and colour photographs.

6. Eocene marls: Yellowish to reddish brown marls are characterized by subdued topography low relief, highly cultivated, light grey tones in black and white photograph and reddish brown with white specks (settlements, agricultural areas etc.) in colour photograph.

7. Eocene Flysch : Consist of thinly bedded alternate bands of grey marls and greywackes. Graded bedding, ripple marks, slump zones and other sedimentary structures are also noticed. At places they show contortions and microfolding.

   On photographs they are characterized by moderate relief with discernible bedding traces, subrectangular drainage pattern, drainage density rather high, fairly vegetated, and showing medium to dark grey tones. In colour photograph the unit shows medium bluish green colour.

8. Eocene clay marl: Bluish grey marl with siltstone and greywackes are characterized by thin linear ridges (photo 4) having dipslope with good vegetation and face slope having less vegetation resulting into lighter tones. The unit shows small flatirons at many places.

9. Oligocene marls: Have a gradual transition from the Eocene clay marls and are marked by the appearance of red shales and coarse, cross bedded brown sandstones and yellowish brown marl.
   The unit is characterized by low to moderate relief dense dendritic drainage, supporting good cultivation and vegetation, and marked by light to medium grey tones and reddish brown, white, and bluish green colours in colour photograph.

10. Oligocene conglomerate: Consists of pebbly sandstone, conglomerate and thin reddish brown clays.
    Characterized by resistant high relief dendritic drainage pattern, good vegetation and medium to dark tones. In colour photograph it shows reddish brown and bluish green colours.

11. Miocene rocks: Consists of light grey marls, yellowish earthy gypseous marls, conglomerate and occasional limestone bands.
    Characterized by subdued topography, low relief, good cultivation and light grey tones in black and white photographs and light greyish brown colours in colour photograph.

12. Quaternary: Consists of older and younger river alluviums, restricted along river valleys. The unit is characterized by flat topography and very good cultivation. Younger alluvium shows dark grey tones (due to moisture & vegetation) and older alluvium, medium grey tones. In colour photographs the two are represented by dark bluish green and medium bluish green to brownish colours respectively.

A working classification of these rock stratigraphic units and their tentative correlation with the standard geological column is given in the following table.

TABLE IV. Geological classification scheme for the part of south external Pyrences and Ebro basin.

Group	No.	Lithostratigraphic units	Tentative time stratigraphic correlation
Group C	12.	b) Younger alluvium) a) Older alluvium)	Quarternary
Group B	11.	Miocene	Miocene
	10.	Oligocene conglomerate)	Oliocene
	9.	Oligocene marl)	
	8.	Eocene clay marl)	Eocene
	7.	Eocene flysch)	
	6.	Eocene marl)	
	5.	White limestone	upper cret. – Palaeocene
	4.	Brown	upper cretaceous
		—— Unconformity ——	(Jurassic not represented)
Group A	3.	Red beds	Permotriassic
	2.	Palaeozoics-undifferentiated	Carboniferous to Ordovician
	1.	Granite	Intrusive in the Palaeozoics during Hercynian orogeny

6. DISCUSSION OF INTERPRETATION RESULTS

In the following sections detailed interpretability of lithostratigraphic units present in each subframe areas shall be discussed under two main headings namely the lithologic mapping and structural mapping.

6.1. Subframe I - Jaca area

The results of photogeological interpretation of subframe area-I, located around Jaca is given in Plate No. 2, (photograph no. 1, with an overlay).The terrain accessibility of this area and various traverses taken for acquiring ground truth data are shown in Plate 3.

Two schematic geological cross-sectionsof the subframe area are given in Plate 4,in order to facilitate an understanding of the geological set up of the area.

Lithostratigraphic mapping

All the aforementioned lithological units except the miocene, are present in Jaca area. All the units with the varrying degree of interpretability, can be detected and discriminated from the others but their identification to the specific lithological type is not possible. However considering the degree of erodability and other topographic features,density and type of drainage etc., a broad category of lithological type may be assigned, to a lesser degree of confidence. Stereoscopic vision can help much at the identification stage as it adds another dimension and hence adds many clues to the characteristics of any lithological unit. The precise identification of different lithological units, has therefore been made possible with the help of ground truth data either in form of existing geological maps or acquired through field checks.

Granite which occurs in the northern part of the subframe occupies a higher topography in the central Pyrenees. Its tone and drainage characteristics and resistance to erosion reveal the identity of this unit. The Palaeozoics generally lack good bedding and therefore reasoned to be highly folded and metamorphorsed.

Skylab photograph of Jaca Area
(Subframe - I)

Any further differentiation of smaller units in this group is not possible and hence they have been mapped as undifferentiated unit. The red beds are conspicuous due to their colour. All the three form a group which has broad characteristics of less or no development of bedding and partial metamorphism.

The overlying rock units namely brown limestone, white limestone, flysch, marls and conglomerate from the second group of rocks which are essentially sedimentary and show good bedding planes and are traceable to long distances. This group of rocks show gentle open type of folding. Within this group the two limestones are very well delineable due to their colour and tone and their resistance to erosion. The flysch zone, although separable with the underlying white limestone and marl, could only be identified after the ground check. The different marls are separable but their chronological relationship is hard to establish till the structure of the area has been worked out. Oligocene conglomerate, occupying the core of oligocene synclines, could be easily discriminated from the lower unit due to its conspicuous reddish brown colour and resistance to erosion. Lateral and vertical facies variations exist between the Eocene units (e.g. Eocene marl to Flysch to clay marl) (E. ten Haaf et al. 1971). However, these variations could not be interpreted from the Skylab imagery.

The third group comprises the river alluvium which, in this subframe, is present in the southern portion only. Flat disposition, good cultivation and their configuration along the Ebro river valley are the characteristics of lithostratigraphic units of this group.

<u>Structural mapping</u>: For working out the structure of an area the attitude and disposition of different rock units present in the area, are of first importance. The different elements which are required for a successfull structural mapping may be mentioned as dip slopes, hog backs, flatirons, strike ridges, fold closure, shifting along faults, joint pattern, lineaments etc. It may be emphasized here that a monoscopic interpretation has serious handicaps in establishing various dip criteria especially when the dips tend to become steeper (dip slope $\simeq$ face slope). Dip slopes are common in the thickly bedded limestone units (4 and 5). They are also noticed and successfully interpreted in the marly units of Eocene and Oligocene. Strike ridges are very common in the Eocene clay

marl unit (8). A strike ridge east of Jaca is seen in photograph no. 4. Overturning of the dips is not identifiable in the photograph. The overturned dips of 'white limestone' could not be established untill the field check (photo 5). Fold closures are very well identified especially when alternating resistant and not resistant rock units are present. The Eocene and oligocene fold closures of the area have been successfully identified. The cretaceous-Eocene sequence show cross folding east of Riglos. A shallow broad oligocene syncline near Jabarella is shown in photograph 6. Faults along the strike of the rock formation are hard to identify e.g. north of Biescas,between white limestone and Eocene flysch. On the other hand those faults which cut-off certain lithological units e.g. near Riglos,have been clearly identified. Minor faults, near the resolution limit are obviously not identifiable.

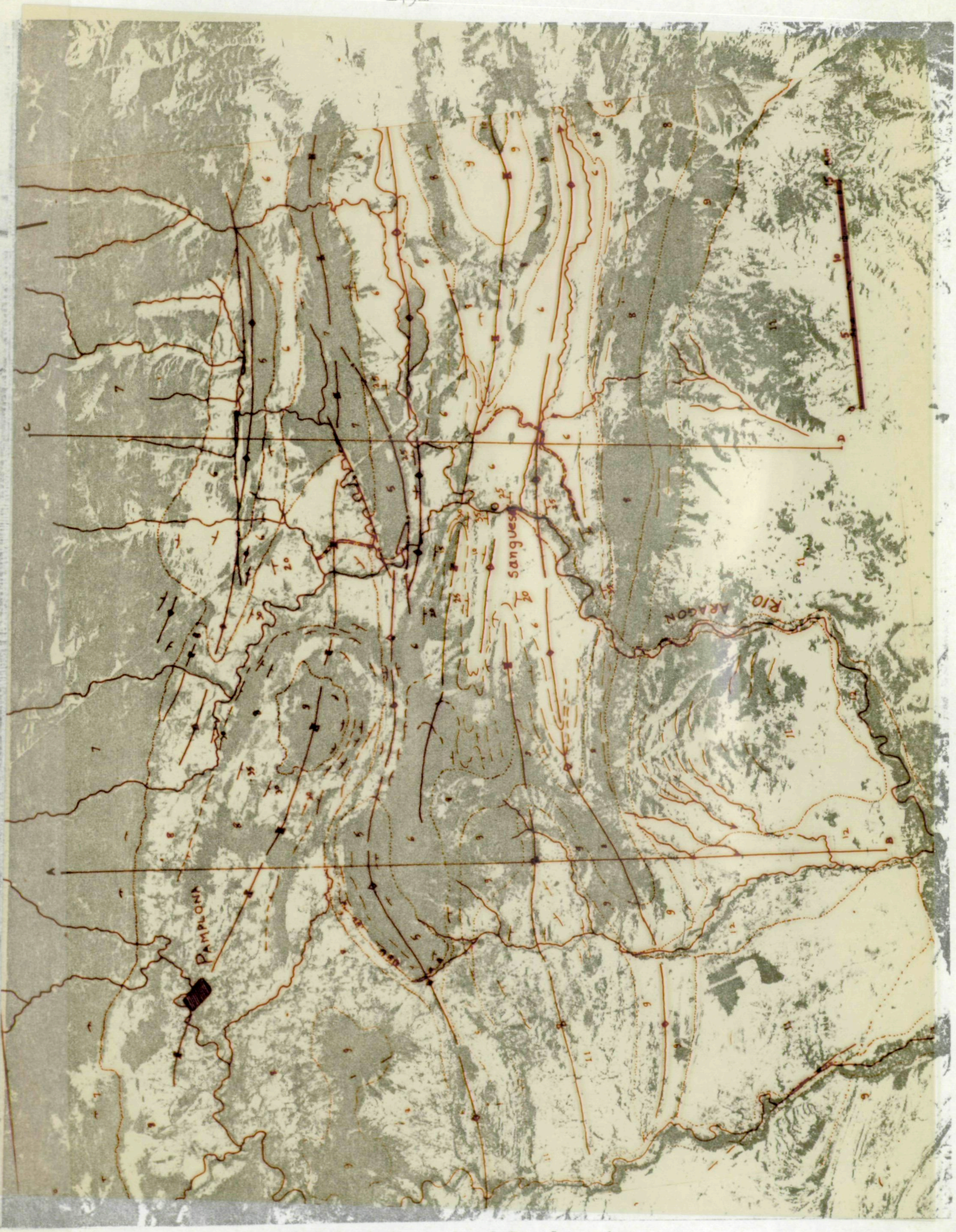
Joint pattern is too small a feature to be identified on this scale, however megalineaments e.g. one along the river south of Riglos, have been traced for quite a good distance.

6.2. Subframe II. Pamplona Area

Subframe II covers an area around the towns of Pamplona and Sanguesa. The results of interpretation have been given in Plate no. 5 (photograph no. 2 with an overlay), the terrain accessibility and the traverses made for field check are shown in Plate 6, and two schematic geological cross-sections of the area are given in Plate no. 7.

An important feature of the photography in this area is that a strip in the middle has stereoscopic coverage, the advantages of which in both lithostratigraphic and structural mapping have already been emphasized. There are certain geomorphic features which have been noticed in the area. An abandoned old channel was located south of Sanguesa. A number of ephimeral streams were noticed in an area south-west of Sanguesa. Two man-made features which were detected and discriminated before, were identified during the field check as

Photograph No. 2



Skylab photograph of Pamplona Area
(Subframe - II)

limestone quarries and a canal. The quarries (shown exaggerated in the map) (photo 7) appear as minute white specks against a darker background of forested area. This strengthens the oft-mentioned fact that with higher contrast it is possible to detect objects below or near resolution limits. The canal appears as a zig-zag dark line branching from a river. One would tend to put it as a tributary of the river, however sharp bends and straight segments indicate a human interference and the field check has established it as a canal.

Lithostratigraphic mapping

The number of lithostratigraphic units present in this area are less than subframe I. No unit below 'white limestone' (5) are exposed in the area. The precise boundary delineation is possible for the units 'white limestone' (5) and oligocene conglomerates (10) while it was less precise in case of quarternary and least in case of different marl units of Eocene and oligocene. However, generally the marly units have interbedded harder bands of Flysch or clay which could be separated out with less difficulty. Assigning and identifying the marly units in their chronological order was partly done by inferential methods of interpreting structural set up of the units and partly through ground truth data.

Structural mapping

A number of dip slopes and strike ridges have been observed and successfully interpreted in the area. This was possible with much ease and greater confidence in the region of stereoscopic coverage which includes a synclinal fold closure caped by oligocene marl and a folded sequence of Eocene litho-units, NNE of Sanguesa. (Ref. Plate 5). Major structural trends, faults and a mega-lineament located in the south-western corner of the area were successfully interpreted. Regarding identification of faults, the general rule applies here as well, that the faults which shift or truncate distinct lithological units, are easily identifiable while those along the strike are noticed only after the field check.

6.3. Subframe III. Calahorra Area

The Subframe III covers mostly the area north of Ebro river. Calahorra town is situated on the southern bank of Ebro river. The geological map as interpreted with the help of Skylab imagery is presented in plate No. 8 (photograph no. 3 with an overlay). The general terrain accessibility map is given in plate 9 and two schematic geological cross-sections of the area in plate 10.

The cultural feature which has been especially noticed in this area is a road near Alfaro (ref. plate 9) which has forested strips on either side and thus appears on the B & W photograph as a dark line. Other roads are also visible where there is high tonal contrast e.g. white metalled road passing though dark cultivated areas and so on. An important geomorphological feature which is typically present in this area is flatirons in oligocene marl having intercalated hard marly limestone units (ref. plate 8). The sequence has face slopes forested while the dip slopes are bare with hardly any vegetation. This results into a pattern of alternating light and dark strips on the photograph (photo 8).

Lithostratigraphic mapping

The lithologic units below the 'white limestone' (5) are not exposed in the area. The Eocene and Oligocene marls are present and their interpretability is subject to the same general remarks as has been mentioned in the earlier sections of the report. Eocene flysch (7) and Oligocene conglomerate (10) are not present in this area. The quarternary alluvium (12) is separable into two distinct units: an older alluvium characterized by brownish colour and lighter tone due to less moisture, and a younger alluvium by darker tones and very good cultivation. Their general configuration within the river valley also helps in identification of the two units.

Photograph No. 3

Skylab photograph of Calahorra Area
(Subframe - III)

Structural mapping

Besides the structural trends and rock attitude elements, which have been successfully interpreted, there are two geolineaments crossing the entire breath of the area. One of these, trending approcimately in a E-W direction, runs north of Calahorra while the other, slightly oblique to the previous one, passes through Alfaro. The only major fault present in the area, cuts across the folded units of Oligocene-Miocene rocks. A fracture lineament is present in the upper western part of the area, along which a tributary of Ebro river is aligned for some distance. However, no apparent dislocation of the corresponding lithological units on either side of the fracture, has been noticed.

7. COMPARISION WITH EXISTING GEOLOGICAL MAPS

The following geological maps are available on the subframe areas:

Subframe I – Jaca Area

1. Geological map of Spain on 1 : 1,000,000 scale. 1A Edicion del Mapa Geologico de España y Portugal Peninsulares, Baleares y canarias del Instituto Geologico y Minero de España, 1965.
2. Mapa Geologico de la province de Huesca, scale 1 : 200,000. Publicado Por el Instituto Geologico y Minero de España, 1957.
3. The map accompanying a paper entitled "The South external Pyrenees of Huesca by E. ten Haaf, R. van der Voo, and H. Wensink, Utrecht", on scale 1:175,000, 1971.

Subframe II – Pamplona Area

1. Geological map of Spain on 1 : 1,000,000 scale (ref. above), 1965.
2. Mapa Geologico E 1 : 200,000 Pamplona (6-13 sheet) and Tudela (22 sheet). Instituto Geologico y Minero de España, 1970.

Subframe III – Calahorra Area

1. Geological map of Spain on 1 : 1,000,000 scale (ref. above).
2. Mapa Geologico E 1 : 200,000 Logroño (21 sheet) and Tudela (22 sheet). Instituto Geologico y Minero de España, 1970.

In order to assess the interpretation results a qualitative comparision has been attempted in the following paragraphs.

7.1. Comparision with geological map of Spain on 1 : 1,000,000 scale

The map covers all the three subframe areas of Jaca, Pamplona and Calahorra and therefore a generalized comparison of different rock stratigraphic units present in the three areas shall be considered. It may be pointed out at this stage that a unit by unit comparision of the two maps, having a wide difference in their scales, is neither feasible nor a fair proposition as discrepancies are bound to crop-up due to scale limitations. However, a basis of comparision does exist as the original scale of Skylab photography was about 1 : 2,800,000.

The classification scheme followed in the two maps is given in the table V. It may be noticed that further subdivision of sedimentary units e.g. Oligocene and Eocene rocks has been possible on skylab interpreted map while slightly metamorphosed and structurally complex rocks of Palaeozoics remain undifferentiated. The interpretability of a normal aerial photograph also shows similar behaviour.

As regards the spatial distribution of the rock stratigraphic units, the outcrop patterns of most of the units compares very favourably. However, the quarternay deposits are traced and demarcated more accurately with the Skylab photographs.

TABLE V. Classification schemes

On 1 : 1,000,000 map	On Skylab interpreted map 1 : 270,000 scale
Quaternary	Quaternary
Miocene	Miocene
Oligocene	Oligocene conglomerate Oligocene marl
Eocene (Nummulitics)	Eocene clay-marl " flysch " marl
Cretaceous superior	White cretaceous limestone
" inferior	Brown " "
Permo-Trias	Red beds Permo-Trias
Carboniferous Devonian Silurian Cambrian	Palaeozoics undifferentiated
Metamorphics Acid Plautonics	Granite

7.2. Comparision with similar scale maps

7.2.1. Jaca area

Jaca area has two maps on 1 : 200,000 and 1 : 175,000 scales respectively. The first one is an old map published in 1951 and the second one compiled and published in 1971. The number of rock-stratigraphic units delineated on these maps and the Skylab interpreted map is more or less same except that there are further subdivisions in the plaeozoics and a few smaller horizons and facies changes in cretaceous and upper groups, in the ground surveyed maps. The reason for this discrepancy may be attributed to the fact that lithological units can not be traced and identified on the photograph which have (1) poor geomorphic expressions

(2) have been subdivided on pure stratigraphic considerations e.g. occurrence of fossils etc. and

(3) too small to be traced on a hyper altitude photograph while they are mappable on detail ground survey on larger scales.

In the spacial distribution the outcrop pattern of the rock units compares very well with the maps. However, some of the sedimentary units e.g. oligocene conglomerate and Quarternary are better traceable on the photograph while those of Palaeozoics are more accurate on the map.

Structural mapping is definitely better on the interpreted map, as it shows far more structural trend lines, folds and faults. A major fracture along the river south of Riglos, is not at all shown on the ground surveyed maps. In fact, for mapping geofractures and megalineaments the Skylab photograph (or any hyper altitude photograph) enjoys a unique position. A number of thrusts shown on the map on 1 : 175,000 scale are either mapped as normal lithological contacts or not mapped at all, on the Skylab interpreted map.
The situation seems to be best explained by either of the following reasons:

1. A low angle thrust plane looks no different than a normal lithological contact.
2. The position of the thrust planes is debatable and they do not exist. That is why perhaps the other ground surveyed map on 1 : 200,000 scale does not show them either.

7.2.2. Pamplona area

The area has been covered by two (IGME) sheets of Tudela and Pamplona on 1 : 200,000 scale. The number of lithological units tally up to formation level. A number of facies and members are indicated on the ground surveyed map which are not mapable on the Skylab interpreted map. It may be realized that a few further subdivisions are still possible to be mapped with a more extensive ground check and also if a smaller area is to be taken for interpretation. With large areas the smaller subdivisions have to be overlookled as they are not traceable for long distances.

The spatial distribution of rock units conforms to the ground surveyed map. However, the ground survey map, curiously enough, shows many lithological units ending at the administrative boundaries of the provinces. This shows that the two teams mapping in the separate provinces had different bias of mapping and they lacked proper regional co-ordination. This problem can be easily overcome when synoptic space imagery is used.

Regarding structural mapping, the major structural trends folds and faults are shown on both the maps. There are, of course additional structural lines and lineaments discernible in the Skylab interpreted map.

7.2.3. Calahorra area

Calahorra area is covered by IGME geological maps of Logroño and Tudela (no. 21 and 22) sheets on 1 : 200,000 scale. A comparision of these maps with the skylab photo-interpreted map on approx. 1 : 270,000 scale leads to similar observations and remarks as has been arrived at while dealing with Pamplona Area, in regard to the classification and spatial distribution of lithological units. Three important differences noticed between the ground surveyed maps and the photo-interpreted map are:

1) Quaternary riveralluvium deposit has been further subdivided into an older and a younger alluvium, in the skylab photo-interpreted map. In the ground surveyed map they have been denoted as a single unit.

2) Presence of two megalineaments, north-west & south-east of Calahorra in the Skylab interpreted map, are not shown on the ground surveyed map. The position can be well explained by the fact that megalineaments are hard to be observed in field due to lack of regional perspective and in that Skylab photographs have the unique advantage.

3) A major fault north of Calahorra affecting the oligocene and miocene rocks has been shown as two small insignificant faults across the lithological contact of the two units in the ground surveyed map. A possible explanation of the discrepancy may be that the detection of a fault across dissimilar lithological units is rather easy as even a small shift in the rock units is well noticed, on the other hand faults passing though the same litho-units lack such obvious manifestations and are liable to be missed.

8. SUMMARY OF SIGNIFICANT RESULTS

As a result of present evaluation study, regarding the capabilities of S190A Skylab photographs for geological mapping purposes the following conclusions can be drawn.

1. Skylab photographs may be successfully utilized for preparing a reconnaissance geological map in the areas where no maps are available or an improved geological map where semi-detailed or reconnaissance maps are available. It has little to add in areas where detailed maps already exist.

2. Large coverage of area and regional perspective provided by Skylab photographs can help better co-ordination in regional mapping.

3. With the help of Skylab photographs, it is possible to delineate major structural trends and other feature like mega-lineaments, geofractures and faults, which have evaded their detection by conventional methods.

4. The interpretability of Skylab photographs is better in areas dominated by sedimentary rocks. The precision in mapping progressively decreases when dealing with igneous and metamorphic terrains.

5. Rock units of smaller extent and having poor geomormphic expressions are difficult to map on the Skylab photographs. Hence some of the units will have to be generalized. Nevertheless, the number of litho units classified on the Skylab photo-interpretated map compares well with that of similar scale ground surveyed map (12 : 14 to 12 : 16).

6. Demarcation of Quaternary river alluvium can be made with better percision and ease with the Skylab photographs and some times it is possible to map smaller units.

7. Time is one single factor which far exceeds many advantages of Skylab photographs over conventional methods. A relatively very short time taken for preparing geological maps of 3 subframe areas (totalling to about 8000 square kilometers area) of reasonable accuracy, during the present investigation, is self-explainatory.

8. Stereoscopic viewing greatly helps in interpretation of structure of the area. If full potentials of the Skylab photographs are to be exploited the future research and development must aim at acquiring adequate stereoscopic overlaps of the photographs.

9. The present Skylab photographs are not good for preparing geological maps of larger than 1 : 270,000 scale. The final compiled map may be reproduced, say on scale 1 : 500,000. The resolution of Skylab photographs is better than all previous hyper altitude photographs. Nevertheless, the resolution has to be still improved if larger scale geological maps are required to be prepared from such photographs.

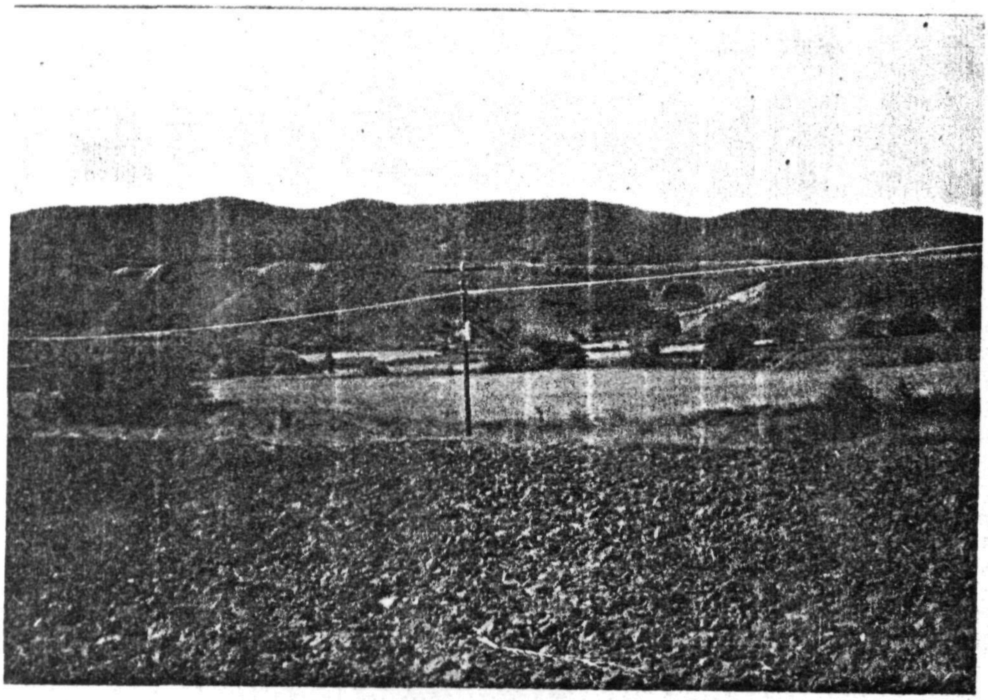


Photo 4. Linear ridge of Eocene clay-marl near Jaca (light toned).

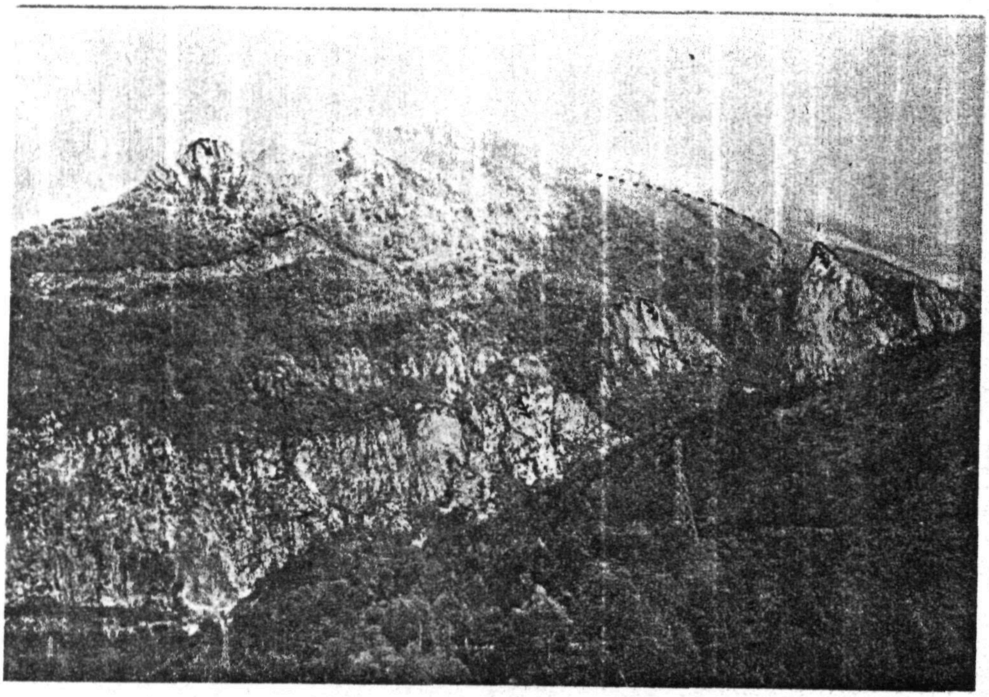


Photo 5. Part of the overturned limb of 'white limestone' near Biescas.

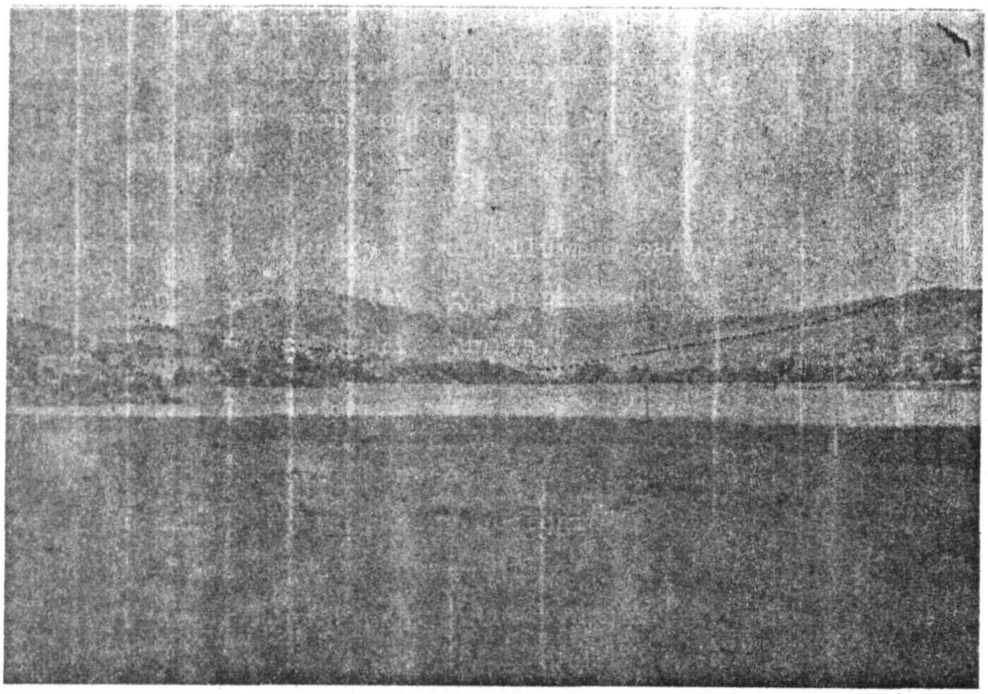


Photo 6. A shallow broad syncline in oligocene rocks south of Jabarella.

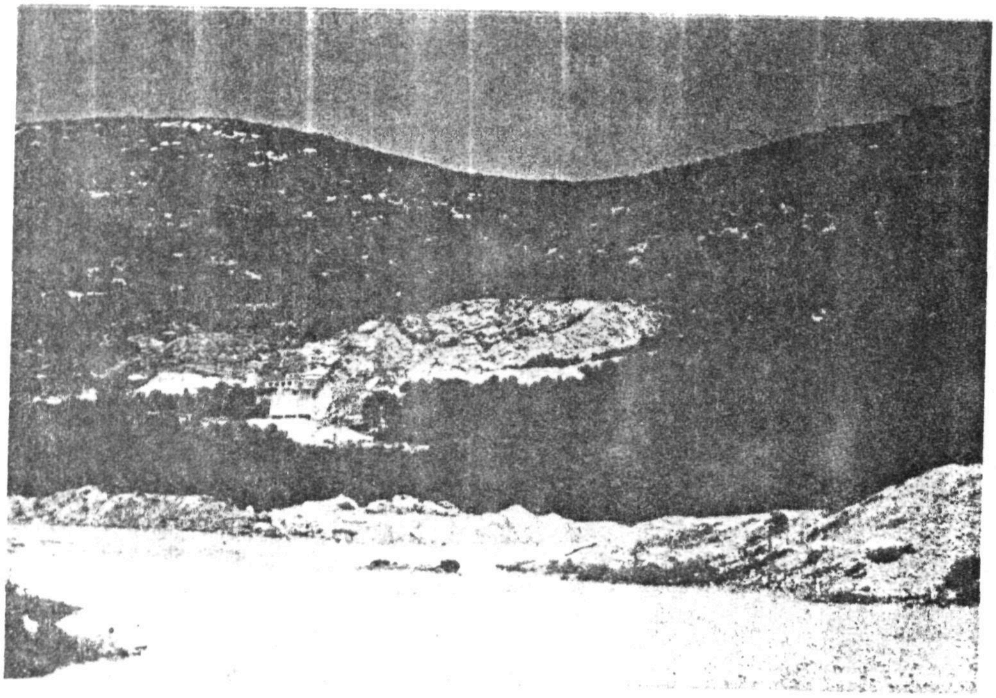


Photo 7. The limestone quarry in 'white limestone' south of Pamplona.

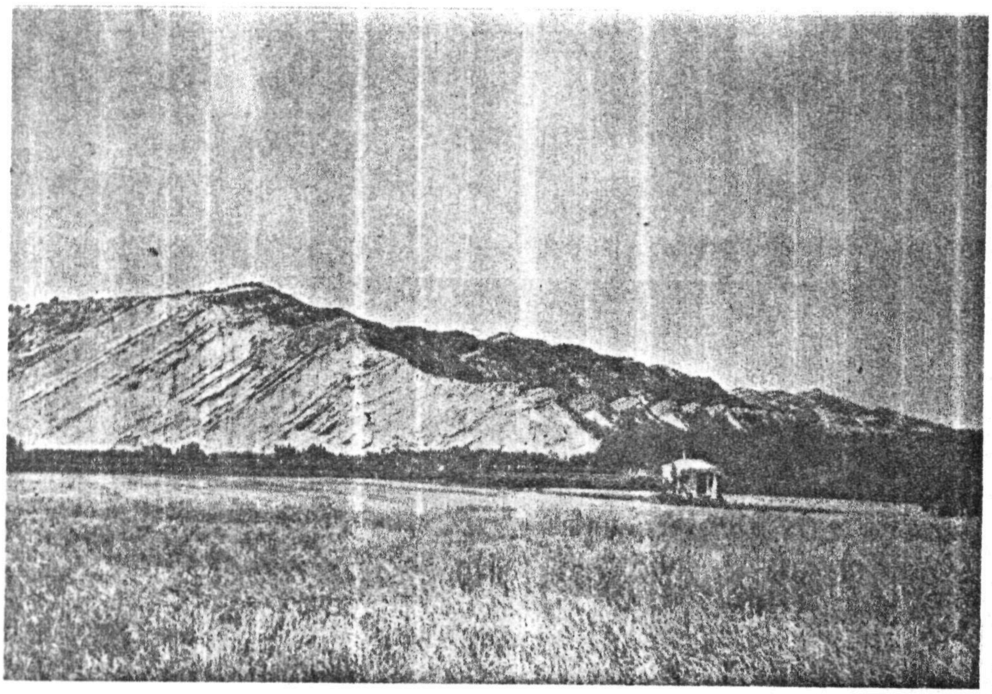


Photo 8. Vegetated face slope and barren dip slope of oligocene limestone & marl near Patella.

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PLATE 1.

LOCATION MAP

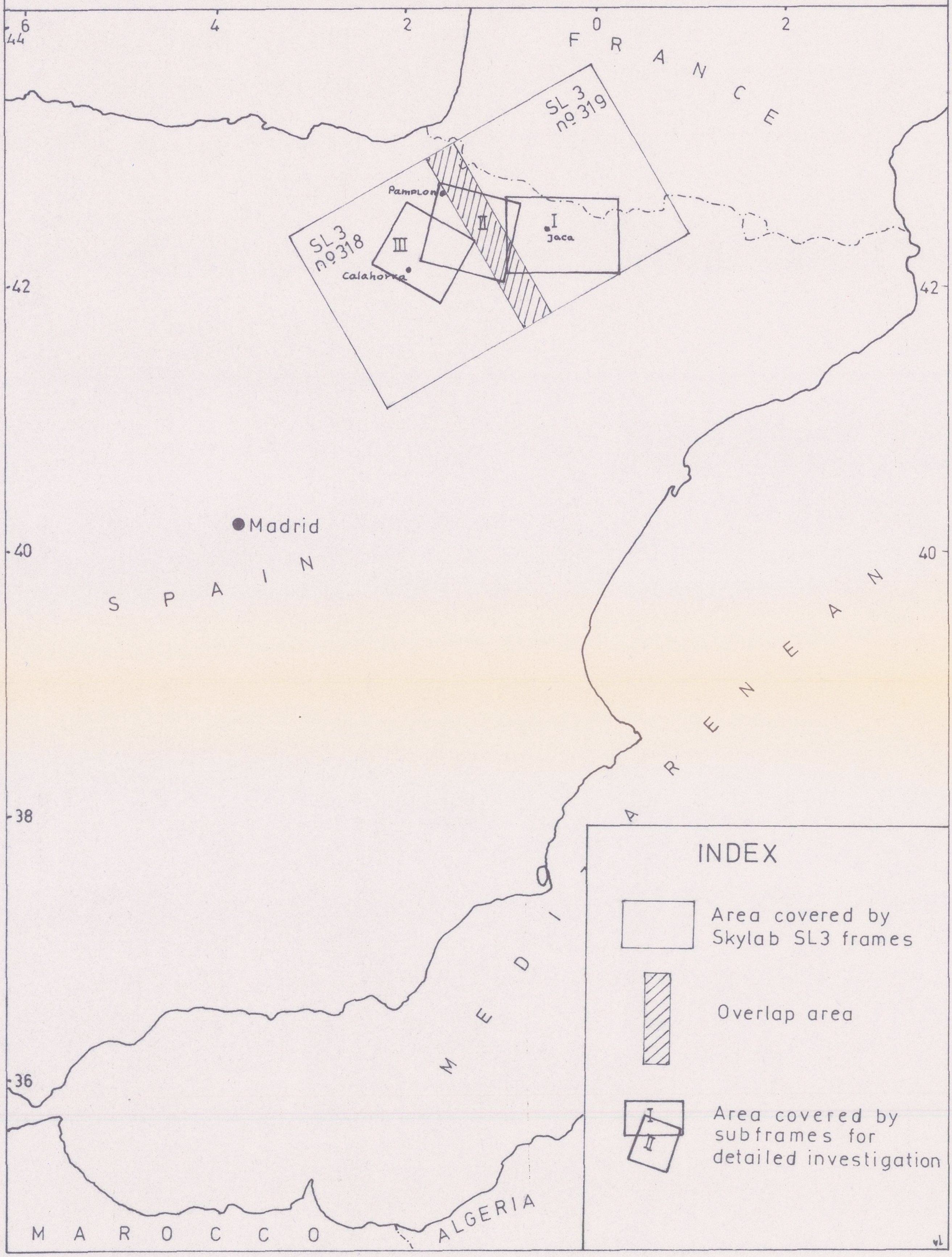
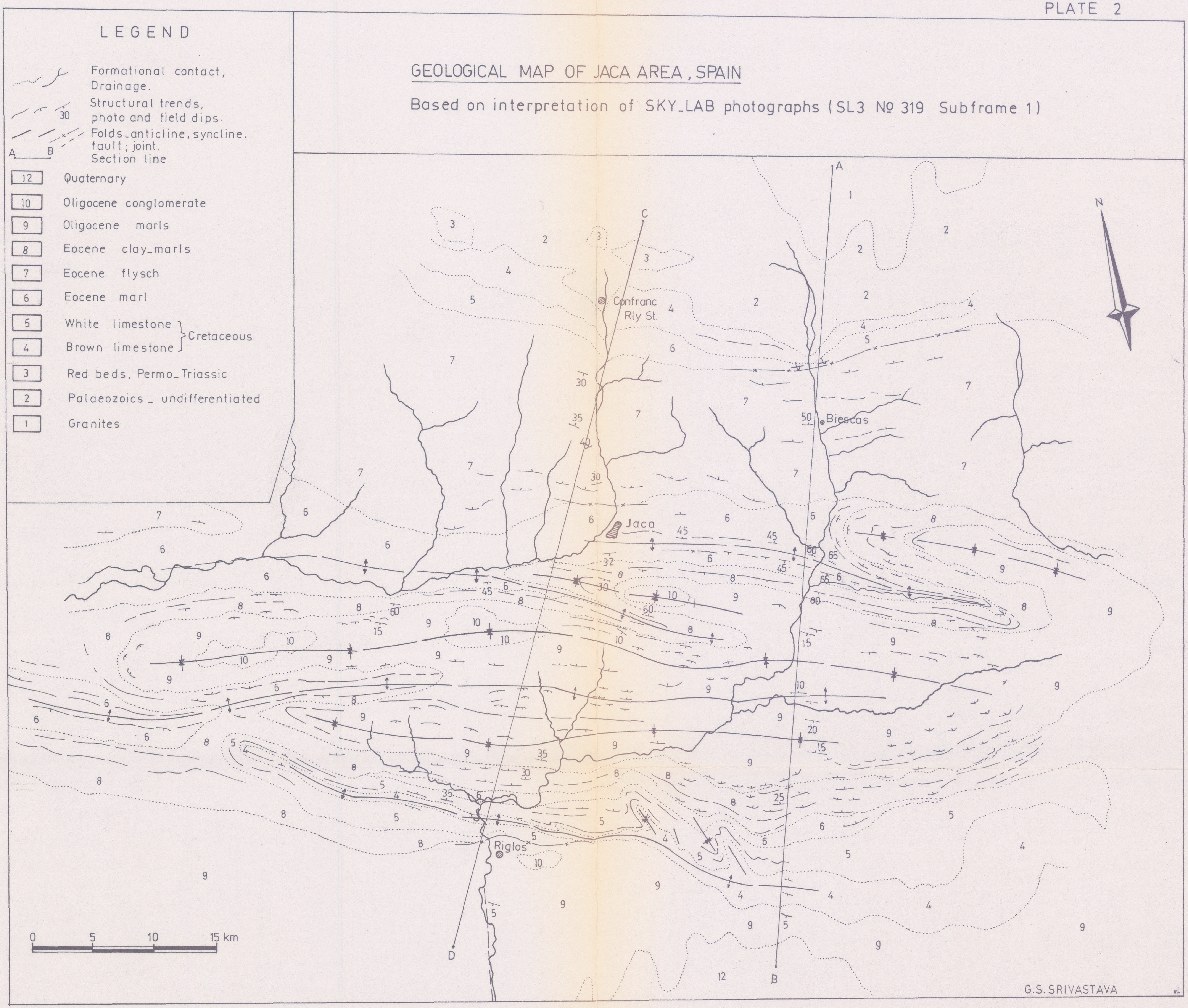


PLATE 2

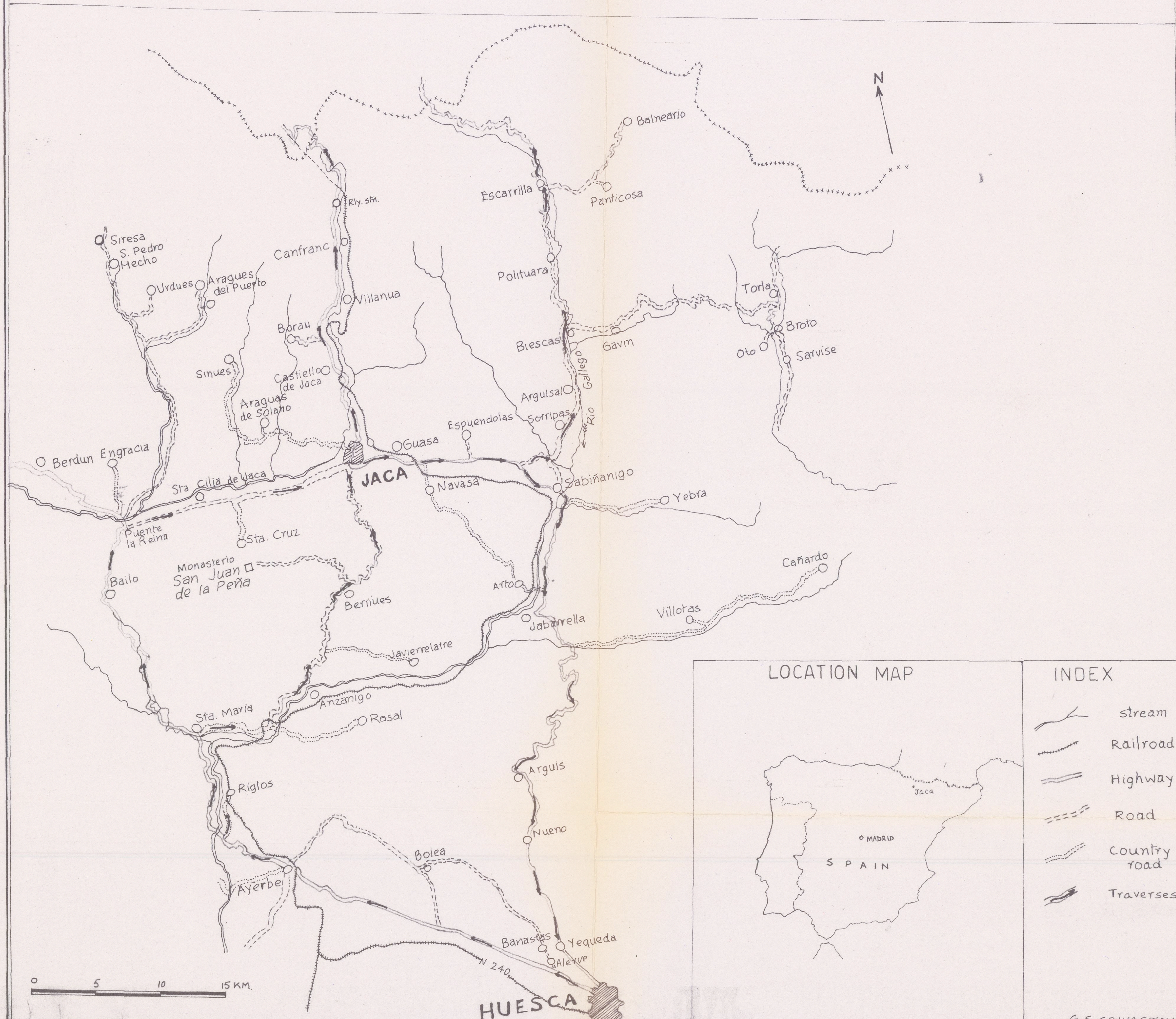


GEOLOGICAL MAP OF JACA AREA, SPAIN

Based on interpretation of SKY_LAB photographs (SL3 № 319 Subframe 1)

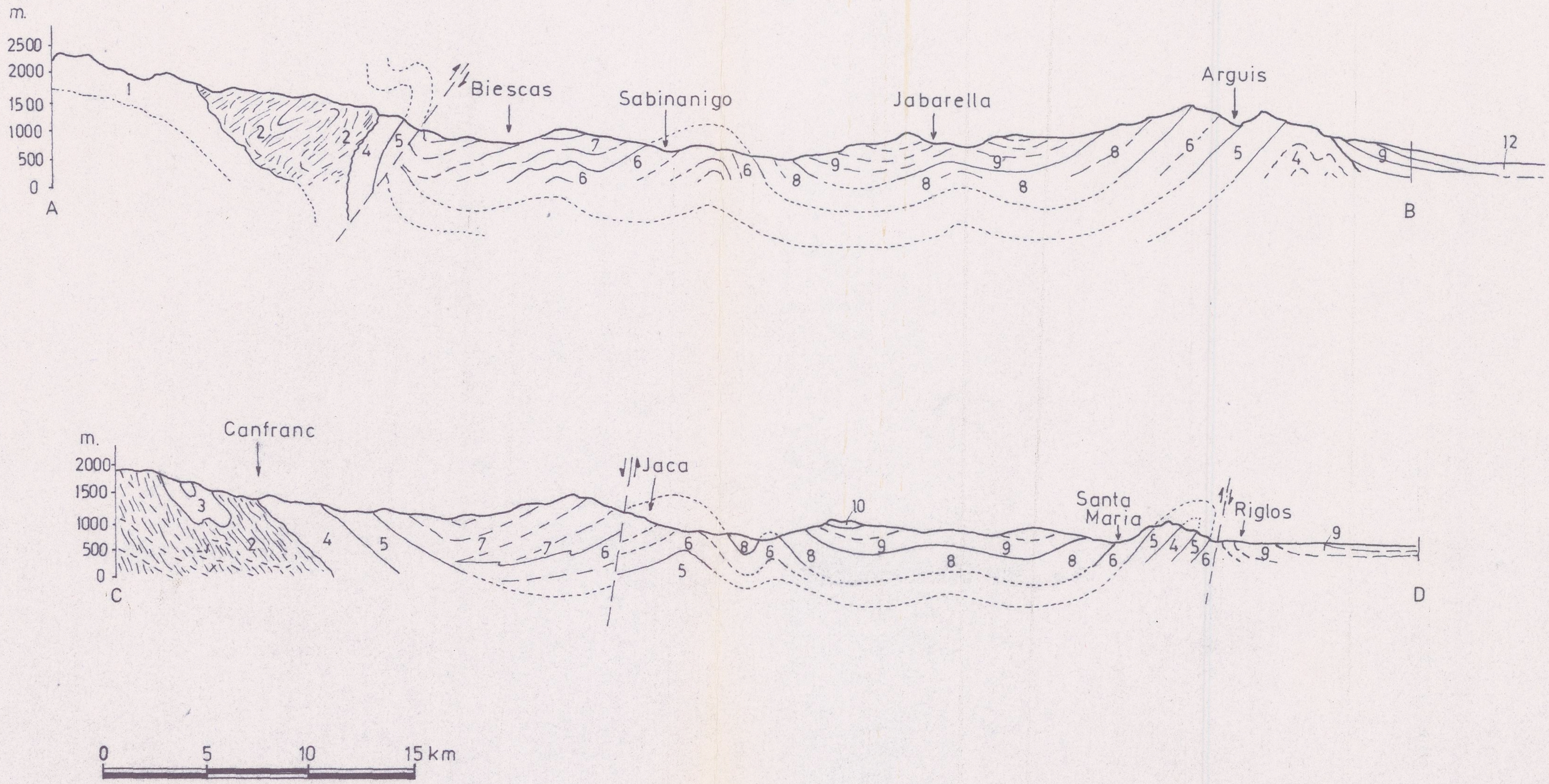
PLATE 3

LOCATION & TERRAIN ACCESSIBILITY OF JACA AREA, SPAIN



G. S. SRIVASTAVA

SCHEMATIC GEOLOGICAL CROSS_SECTIONS OF JACA AREA, SPAIN



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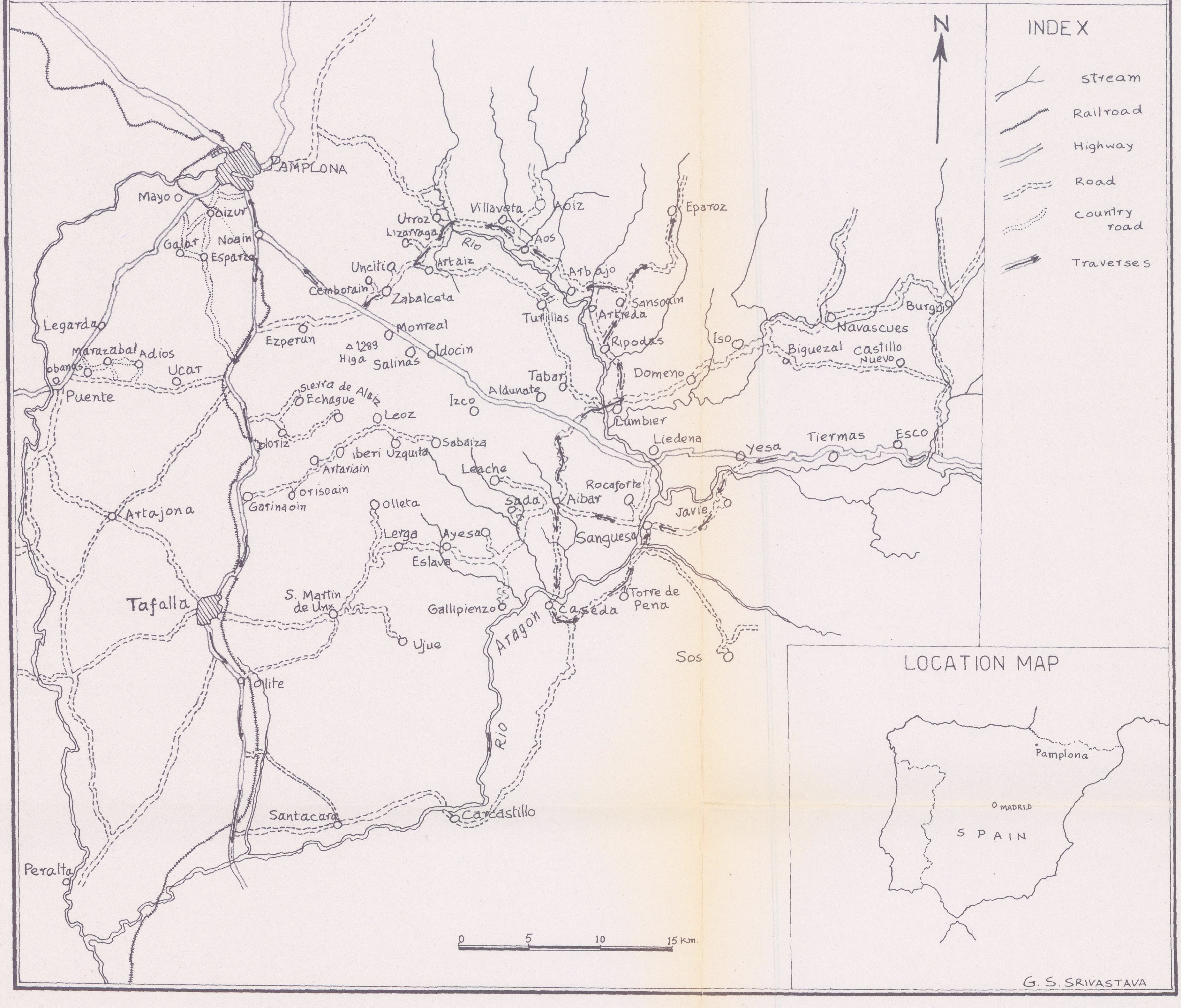
GEOLOGICAL MAP OF PAMPLONA AREA, SPAIN.

BASED ON INTERPRETATION OF SKY_LAB PHOTOGRAPHS (SL3, no.318 SUBFRAME 2)

LOCATION & TERRAIN ACCESSIBILITY OF PAMPLONA AREA, SPAIN



SCHEMATIC GEOLOGICAL CROSS_SECTIONS OF PAMPLONA AREA, SPAIN.

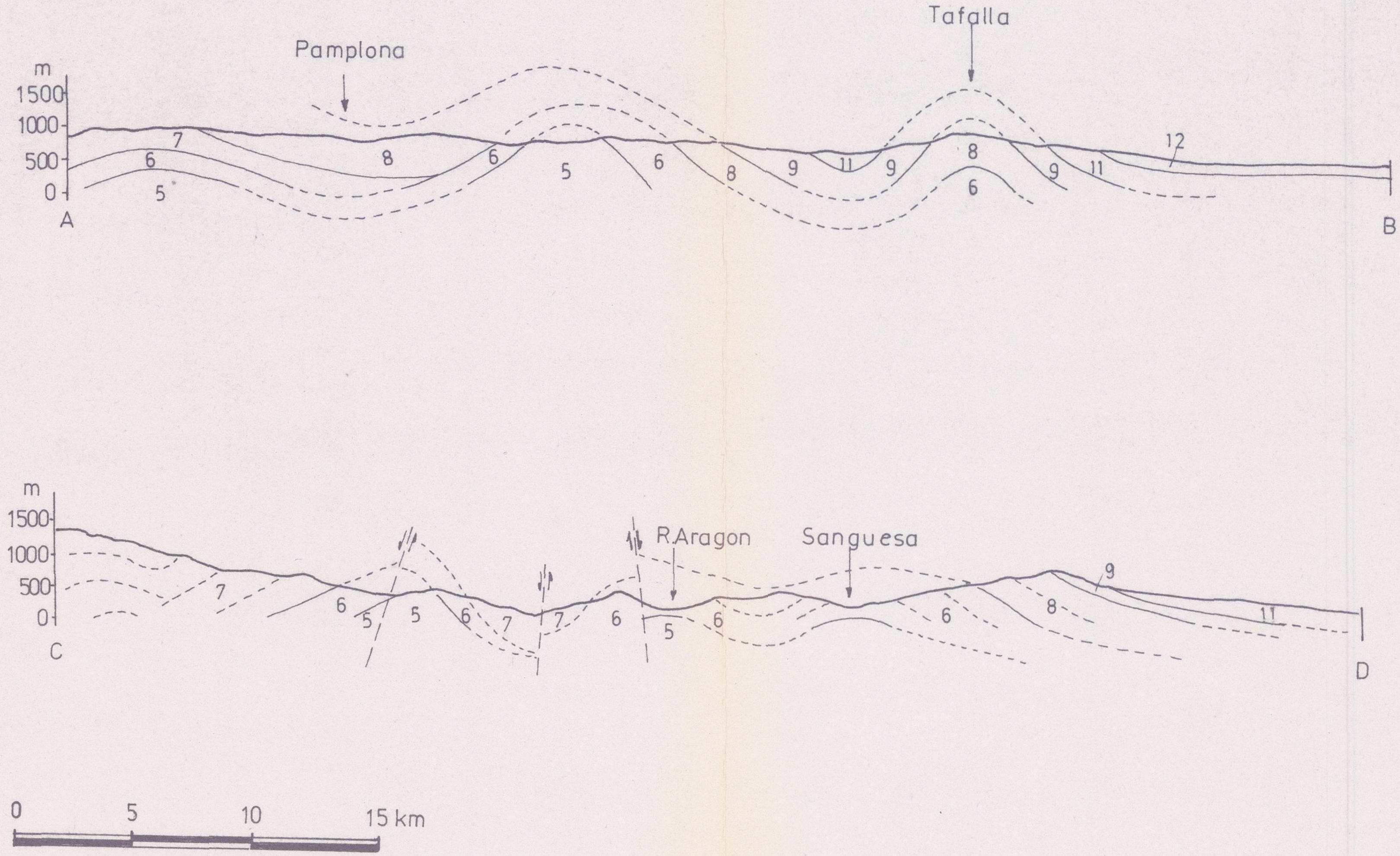


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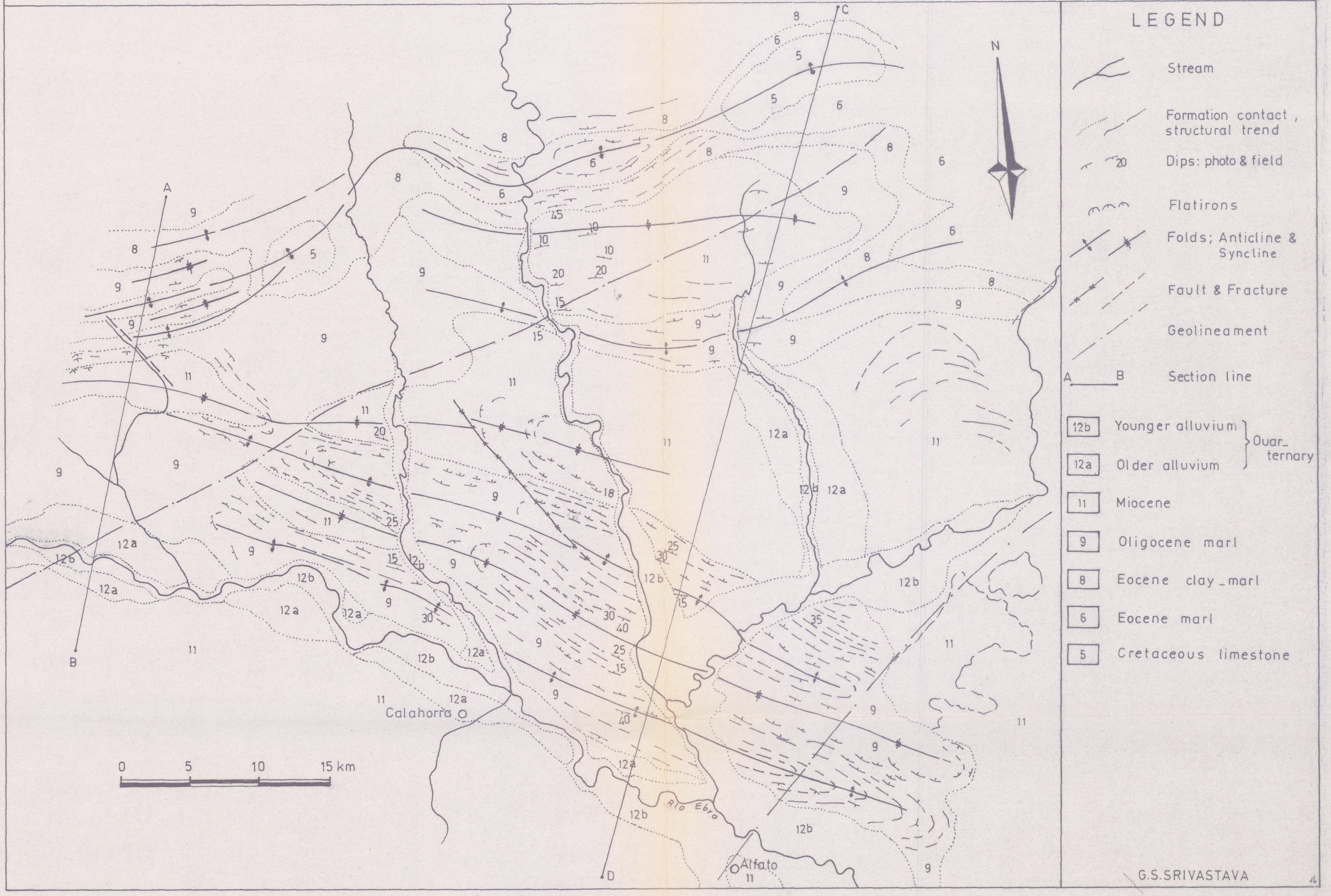
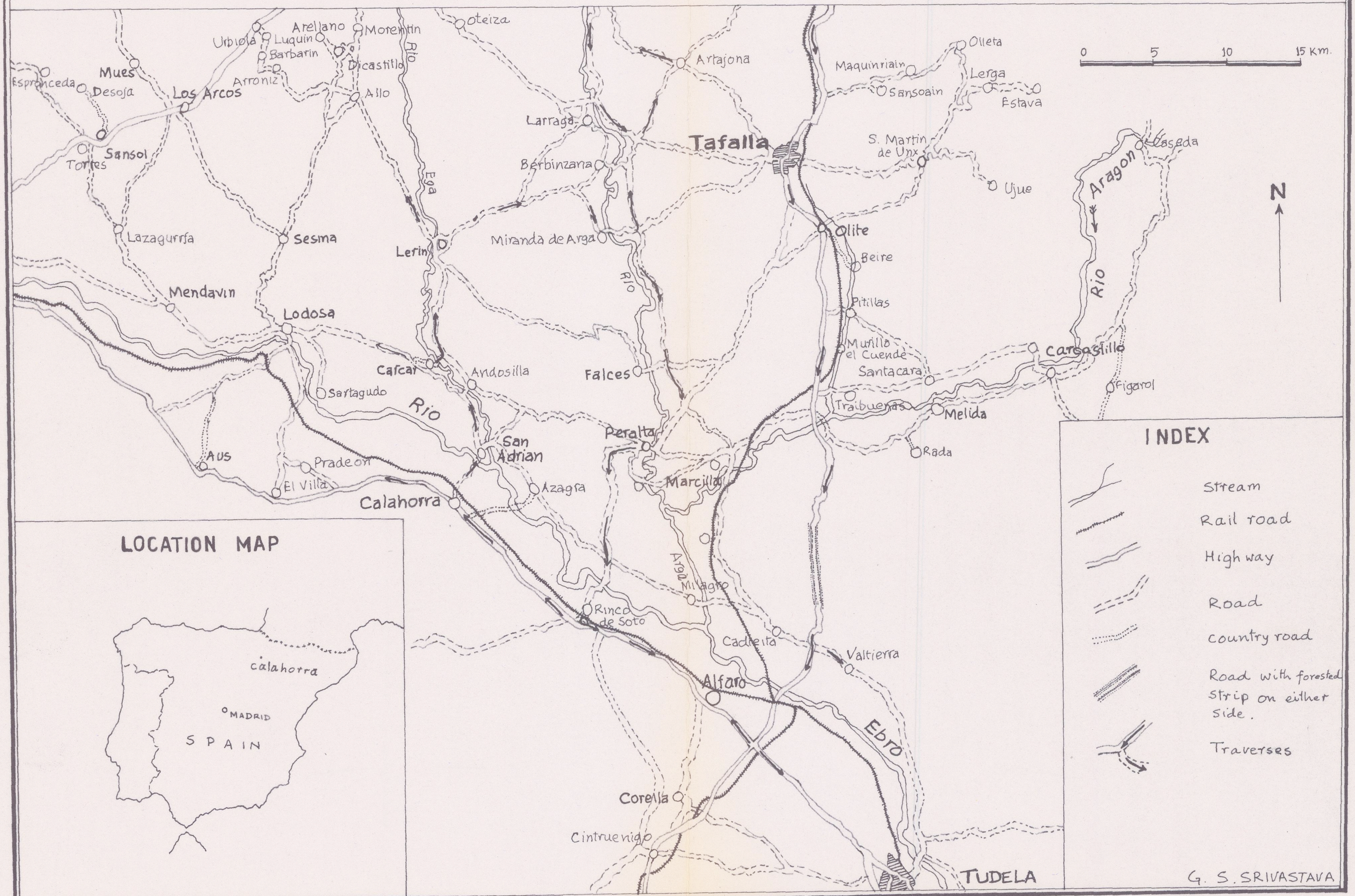
PLATE 8

GEOLOGICAL MAP OF CALAHORRA AREA, SPAIN

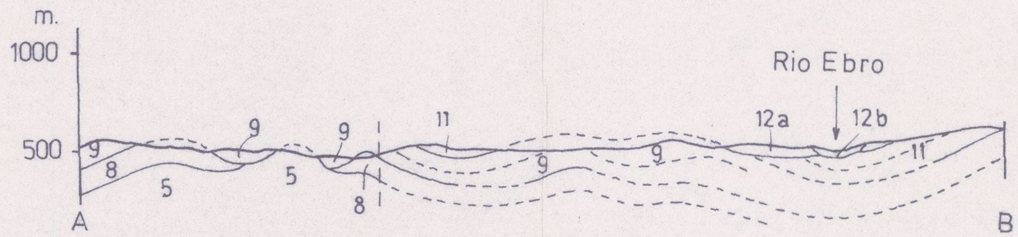
BASED ON INTERPRETATION OF SKY_LAB PHOTOGRAPHS SL3 no.318 SUBFRAME 3.

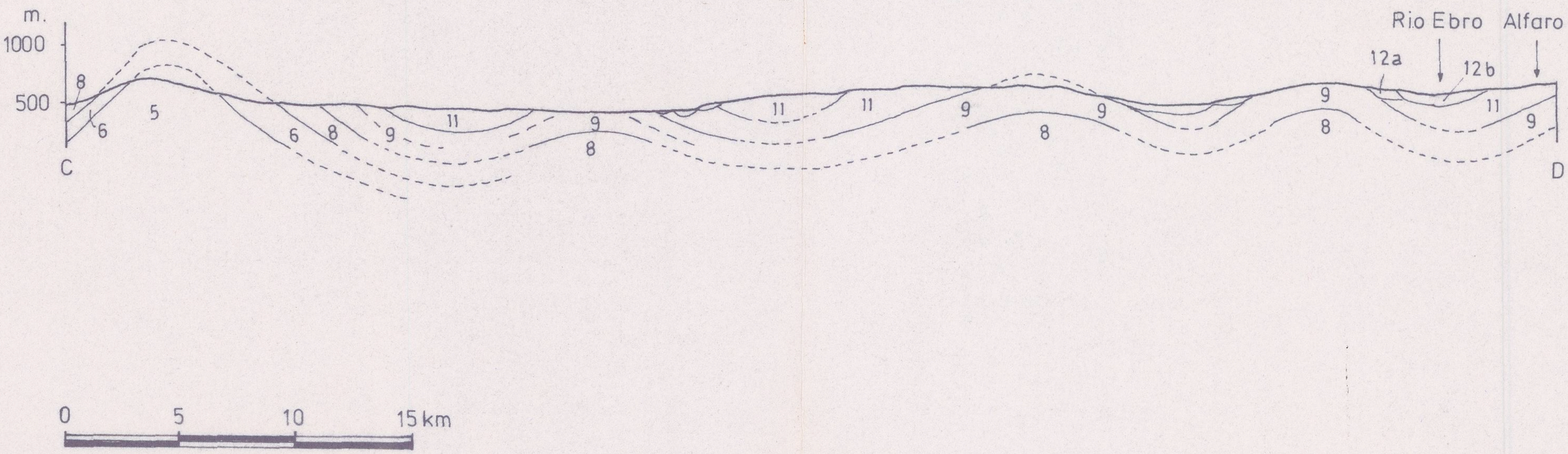


LOCATION & TERRAIN ACCESSIBILITY OF CALAHORRA AREA, SPAIN.



SCHEMATIC GEOLOGICAL CROSS_SECTIONS OF CALAHORRA AREA, SPAIN.





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