Progressive Versus Paroxysmal Alpine Folding in Sinjar Anticline Northwestern Iraq

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ABSTRACT

Analysis of contoured stereographic pi-diagrams for lower hemisphere equal area projections for poles to the bedding planes in the Shiranish, Sinjar /Aliji, Jaddala, Serikagni and Jeribi formations of Sinjar anticline has been carried out. The considerable discrepancy between the pi-diagrams for the Shiranish formation and the Tertiary formations indicate a Late Maastrichtian Alpine folding phase recognized in earlier work. However, the near perfect coincidence between the pi-diagrams for the Tertiary formations is discussed with respect to two possibilities for the nature and timing of folding. Firstly, that folding took place during the Tertiary in progression with deposition of the different formations. Secondly, that folding took place as paroxysmal phase of Alpine folding in the Pliocene times. Circumstantial evidence from the field supports the second possibility.

طي ألبي تقادمي أم فجائي في طية سنجار المحدبة شمال غرب العراق

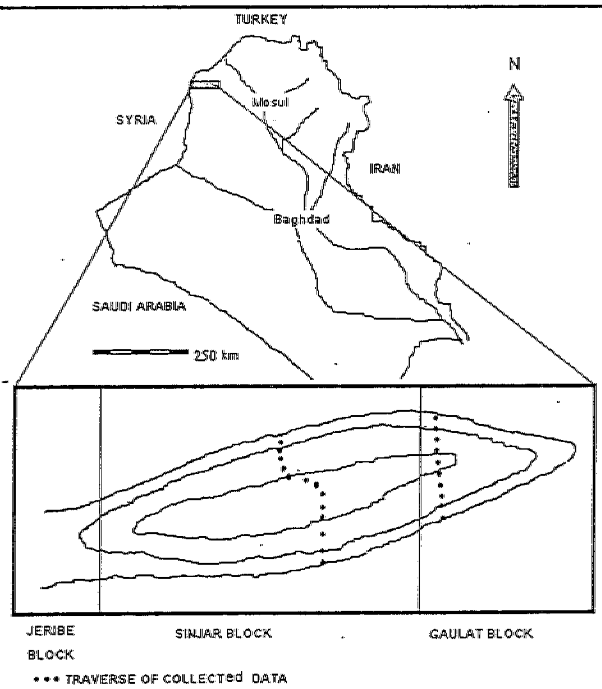
الملخص

أجري تحليل اشكال باي الستيريوغرافية الكنتورية والناتجة من اسقاط اقطاب مستويات الطبقات من النصف الاسفل من كرة الاسقاط لكل من تكوين شرانش، سنجار، عليجي، جدالة، سيريكاكني و جريبي لطية سنجار المحدبة. ان الاختلاف الموثق بين اشكال باي لتكوين شرانش وتكوينات العصر الثلاثي يدل على طور طي للماسترختي المتأخر والمذكور في الدراسات السابقة. ان التطابق شبه التام بين اشكال باي لتكوينات العصر الثلاثي قد نوقشت على ضوء احتمالين يعتمدان على طبيعة وتوقيت عملية الطي. أولا: أن عملية الطي قد حدثت خلال العصر الثلاثي بشكل تقادمي مع عملية الترسيب للتكوينات المختلفة. ثانيا: حدثت عملية الطي الالبي بشكل فجائي في البلايوسين. وأن الدلائل الحقلية المدروسة تعطي الارجحية للاحتمال الثاني.

INTRODUCTION

Sinjar Mountain is a spectacular major anticlinal structure in the northwestern part of Iraq (between longitudes 42° 07 - 41° 39 and latitudes 36° 26 - 36° 15). It reaches a height of 1400 meters a.s.l. The length of its SWW –NEE trending axis is about 75 km in Iraq, and it extends in low level ground for another 25 km in Syria. Its half wavelength is 10 km across the oldest exposed core. Sinjar structure is an asymmetrical anticline with a steeper northern limb, gentle southern limb and a northerly vergence. A major longitudinal normal fault has resulted in the repetition of the northern limb for over 15 km along its structural contours. Three major transverse basement blocks have been recognized underneath Sinjar Mountain (Al-Azzawi, 1982), namely they are the Goulat, Sinjar and Jeribe blocks (Fig. 1).

A -



B -

Al-Fatha Fn.		Middle Miocene
Jeribe Fn	120m	Lower Miocene
Dhiban Fn.	126m	
Serikagni Fn.	355m	
Jaddala Fn.	375m	Upper Eocene to Lower Eocene
Sinjar Fn.	201m	Lower Eocene Upper Paliocene
Shiranish Fn.	560m	Upper Cretaceous

Fig. 1: A Location map . B-Stratigraphic succession of Sinjar Anticline

Sinjar Anticline exposes a number of formations belonging to the Upper Cretaceous and Tertiary with a distinct angular unconformity at the Cretaceous –Tertiary contact (and hence a definite pre-Tertiary folding phase). The exposed formations are the Shiranish Formation of Upper Cretaceous (Campanian – Maastrichtian) age, The Sinjar / Aliji Formations (paleocene – Lower Eocene), Jaddala Formation (Middle to Upper Eocene),Serikagne Formation(Lower Miocene) and Jeribe Formation (lower Miocene). Al-Fatha Formation (Middle Miocene) and Injana Formation (Upper Miocene) are exposed outside the bounds of Sinjar Mountain though they constitute part of the Sinjar anticlinal structure and are affected by the Tertiary fo0lding phase

Sinjar Anticline has attracted over the last few decades a number of researchers who investigated different aspect of the structure, stratigraphy, geochemistry, geophysics and hydrogeology The most conspicuous of these studies are those of Maala (1977), Al-Ubidi (1978), Al-Azzawi (1982), Al-Jumaily (1982), Numan and Al-Azzawi (1992) and Numan (1984,2000,2001) . In this work a total of 488 bedding measurements were taken in the field along two traverses across the Sinjar Anticline in Sinjar and Gaulat block (Fig.1). The data were plotted in the stereographic pi- diagram s and analysed separately for each formation in each traverse with a view to analyse the Alpine folding history in the Sinjar Anticline.

STATEMENT OF THE PROBLEM

Qualitatively Al-Azzawi (1982) and Numan (1984,2000) have pointed out the angular unconformity between the Cretaceous and Tertiary successions within the Sinjar Anticline. This indicates two separate Alpine phases of folding in the Late Maastrichtian and in the Tertiary . However, the nature and timing of folding in the Sinjar Anticline has not had speculations based on quantitative analysis. This is the domain of emphasis in this work. Investigation is required as to whether the Alpine folding in Sinjar especially in the Tertiary succession was concurrent progressively with the deposition of each of the Tertiary formations or whether folding happened in the main at the Pliocene as a paroxysmal phase of folding of the Alpine orogen.

METHODOLOGY

In our attempt to deduce the folding history, field data of bedding planes from different parts of the succession and different structural positions within the Sinjar Anticline were utilized in this investigation. Stereographic pi-diagrams were drawn separately for the bedding data from each of the formations along Gaulat and Sinjar traverse (Fig. 1). These diagrams were drawn for the purpose of finding any major or subtle differences in the direction and / or intensity of folding in the different formations.

RESULTS

Figures (2 and 3) show contoured stereographic pi-diagram of lower hemisphere Lambert equal area projection of poles to bedding planes in the Shiranish, Sinjar/Aliji, Serikagni, Jaddala and Jeribe formations respectively. The attitudes of the pi-axes (i.e. fold axes) and the axial planes (assuming that they bisect the interlimb angles) for folding in each of the above mentioned formations are given in Table (1). The Figures (4) and (5) show synoptically great circles of the axial planes of folds in each of the above formations, the great circles of pi-planes and pi-axes of folds in each of the formations of

Sinjar and Gaulat traverse of the Sinjar Anticline .The presented pi-diagrams show that folding in Sinjar Anticline is of sub-cylindrical type (Ramsay and Huber, 1987). The Pi-diagram for Shiranish Formation (Fig.7) differ considerably from those of the Tertiary Formations (Fig.2 and 3 and Table 1). However the Pi-diagrams for the Tertiary formations show near perfect coincidence between each other except for Aliji Formation whose data are restricted to the core of Sinjar Anticline.

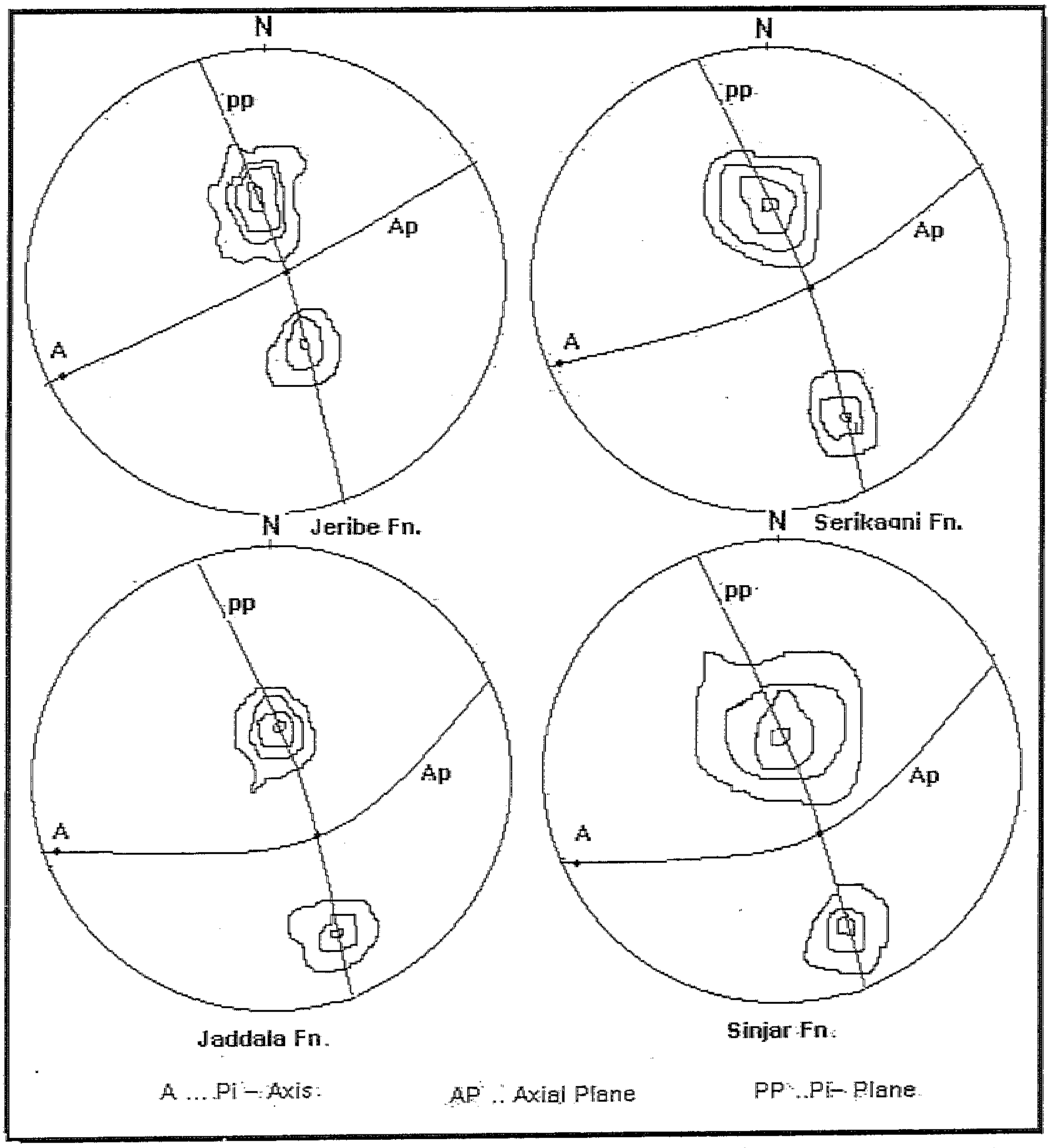


Fig.2: Stratigraphic Pi-diagrams along Sinjar traverse

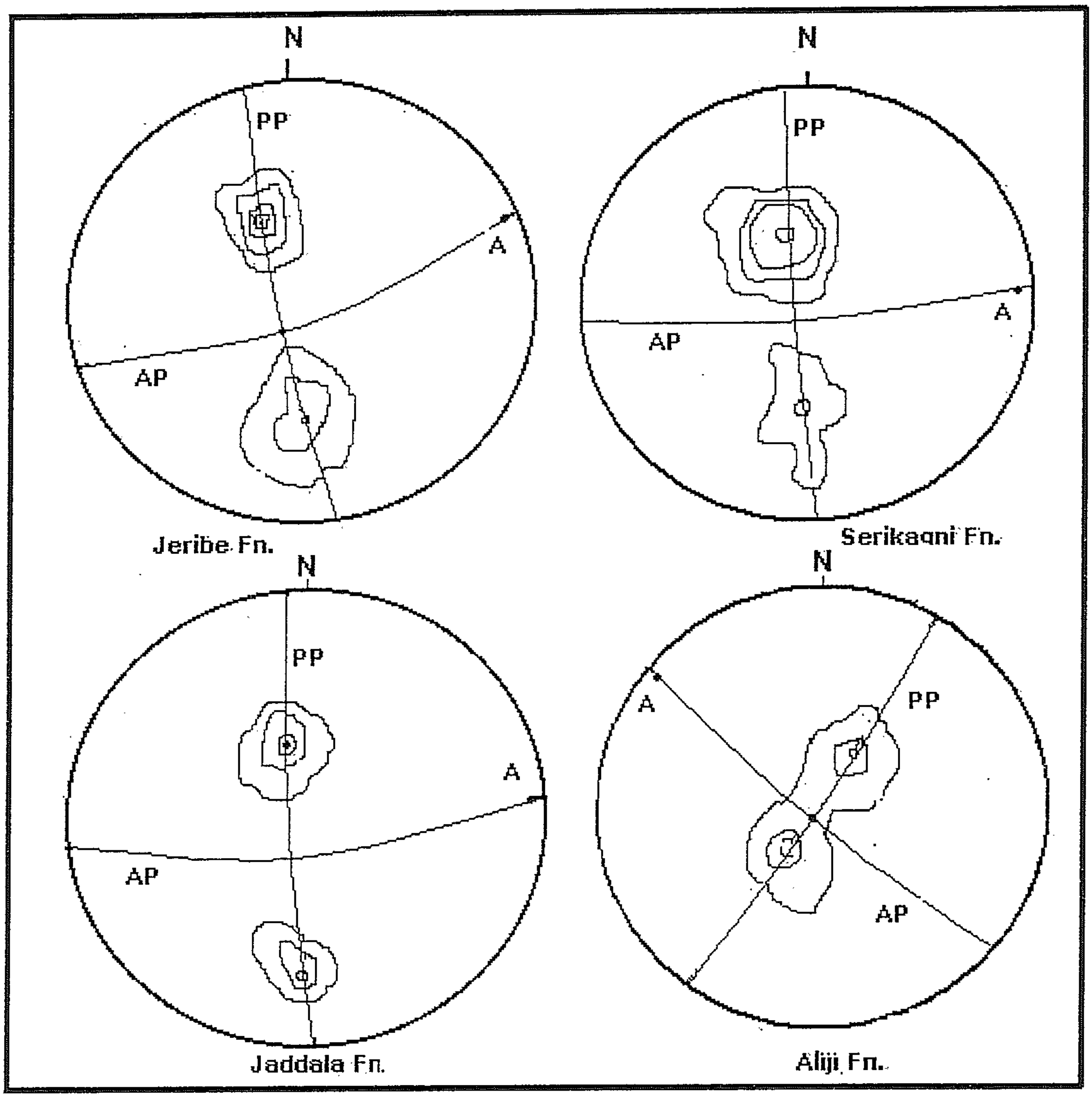


Fig.3: Stratigraphic Pi-diagrams along Gaulat traverse

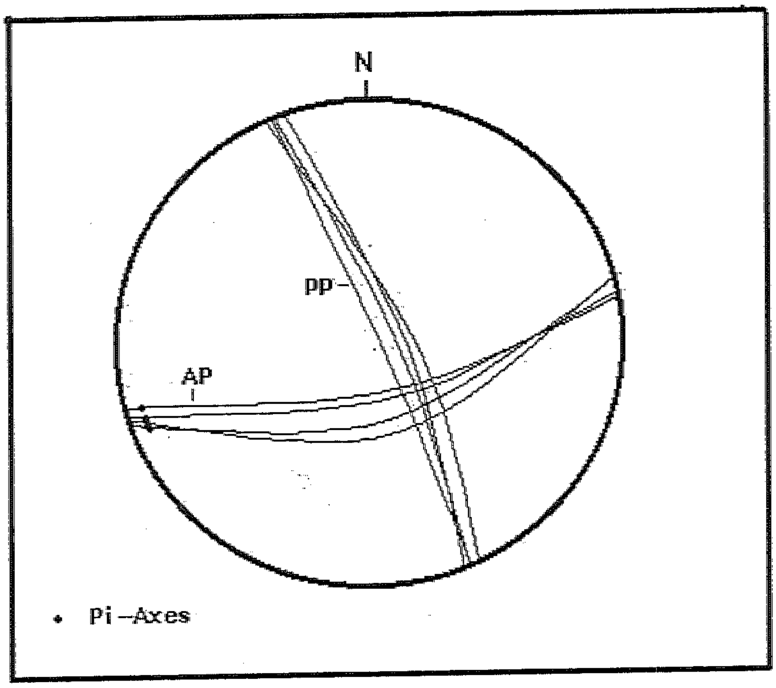


Fig.4: Pi-diagrams along Sinjar traverse

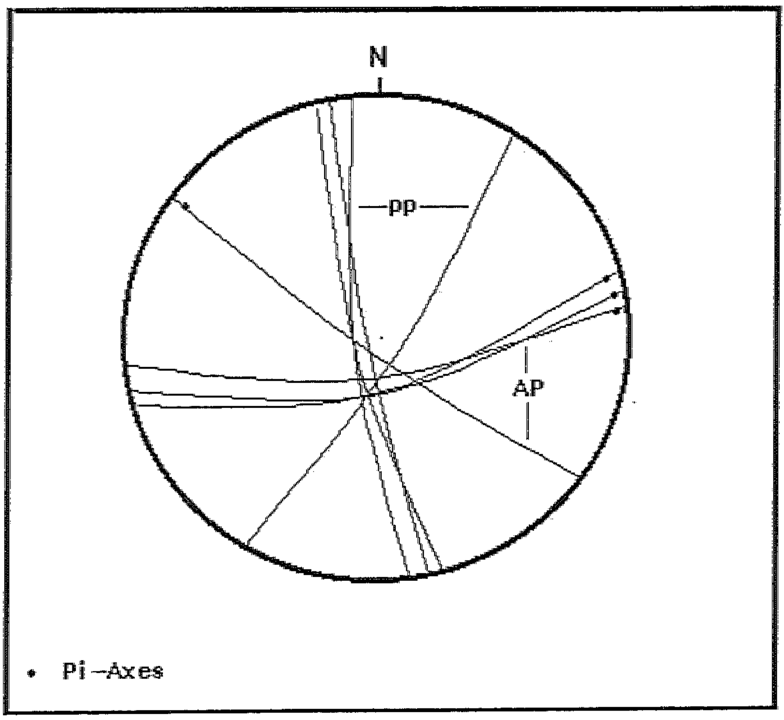


Fig.5: Pi-diagrams along Gaulat traverse

Table 1: Axial planes , Pi-planes and Pi-axes for Late Maastrichtian and Tertiary foling

Formation	Axial plane	Pi-plane	Pi-axis
Sinjar Traverse			
Jeribi	252/87	162/88	252/02
Serikagni	255/72	162/84	252/06
Jaddala	253/64	160/84	250/06
Sinjar	252/62	158/86	250/04
Shiranish (T)	253/80	344/90	074/00
Shiranish (C)	235/84	325/88	054/02
Gaulat Traverse			
Jeribi	256/74	348/86	077/04
Serikagni	263/79	353/84	083/04
Jaddala	266/75	256/85	087/05
Aliji	123/86	212/88	303/02

DATA ANALYSIS AND DISCUSSION

It is well established now that two main Alpine orogenic phases are clearly manifested in the foreland folds belt northern Iraq (ibid). Namely they are the Late Maastrichtian folding which lead to the angular unconformity at the Cretaceous – Tertiary contact and the Tertiary folding. Numan (2000,2001) suggested that these folding phases in northern Iraq are directly related to the plate tectonic evolution of the region. This involved a prolonged period of subduction (Cretaceous to Eocene) of the Neo-Tethyan oceanic crust and eventual continental collision between Arabia, Turkey and Iran which started in the Eocene. These relative movements between the colliding Arabian, Iranian and Turkish plates instigated the Late Maasrichtian and Tertiary folding phases by rejuvenation of displacements along older listric normal faults that were formed during the extensional phase on the Arabian passive continental

margin. Numan (2000) produced analytical evidence that refers the Late Maastrichtian folding phase to drag folding in the sedimentary cover due to prevailing strike –slip displacements along the older listric normal faults in the basement rocks i.e. wrench tectonism and passive orogeny with no shortening of strata perpendicular to the fold axes. By contrast Numan (op.cit) attributed the Tertiary folding phase mainly to prevailing dip-slip reverse displacements along the originally normal listric faults, i.e. compressional orogeny with shortening of strata perpendicular to the fold axes. One of these reverse displacements deep in the basement continued along a cylindrical fault plane of a listric fault and reached the surface as a normal fault, (Fig. 6), that caused the above mentioned repetition of the northern limb of Sinjar Anticline in the manner described by Numan and Al-Azzawi (1993).

The Shiranish Formation is exposed in the core and the northern limb of Sinjar Anticline. A prudent look at the Pi-diagram of folding in this formation (Fig.7A) reveals the two above mentioned Late Maastrichtian and Tertiary phases of folding. Pi-circle (pp2) on Figure (7A) belongs to the Late Maastrichtian phase with the attitude of folding axis at (055/02 point MF). Pi-circle (pp1) on Figure (7A) apparently represents the Tertiary folding with the attitude of the fold axis at (070 /07Point TF). There is thus an angle of 15 degrees between the directions of folding in the Late Maastrichtian and Tertiary.

Since the Shiranish Formation is exposed only in the core and the northern limb of Sinjar Anticline, The attitude of Shiranish Formation in the southern limb cannot be measured in the field. Hence pi-Circle (pp1) on Figure (7A) does not represent the precise Pi-diagram of Tertiary folding in Shiranish Formation.

The more realistic pi-circle for the Tertiary folding in Shiranish Formation is one that takes into account the attitude of the Shiranish Formation in the southern limb of Sinjar Anticline. This could be deduced on Figure (7B) by considering the 35 degrees rotation which happened by Tertiary folding to the gentle Cretaceous northern limb (point **a** on Fig.7A) in the Shiranish Formation and caused it to steepen , rotate and move to position **b** along the great circle **gc1** , A mirror image of this rotation could be constructed for the Tertiary unexposed southern limb in the shiranish Formation. This is achieved by moving the gentle Cretaceous southern limb (point **c** on Fig.7B) by a lesser degree of rotation than the northern limb (because of asymmetry) arbitrarily chosen at 25 degrees to the steeper position **d** along the great circle **gc2**. Point **d** represents the pole to the subsurface attitude of the Shiranish Formation in the southern limb of Sinjar Anticline. The great circle **gc3** thus represents the more realistic Tertiary pi-circle for the Shiranish Formation and its Pi-axis is at 073/00. The attitude of **gc3** conforms well with the attitudes of pi-circles for folding in the Tertiary Formations of Sinjar Anticline. It follows that the more realistic angle between the directions of folding in the Late Maastrichtian and Tertiary is 20 degrees.

The coincidence of the pi-diagrams for different parts of the Tertiary succession in the Sinjar Anticline (Fig.2 and 3 and Table 1) would suggest that folding was purely of the parallel flexural slip type with no disharmony of folding between the different formations of the Sinjar Anticline. As for the timing of the folding of the Tertiary formations, it may be regarded with a view of the two possibilities: -

First: There was a single paroxysmal folding phase that affected the whole of the succession in the Pliocene times and together with the flexural slip folding mechanism explain the perfect coincidence of the pi- diagrams of the Tertiary formations.

Second: That several folding phases affected in progression the stratigraphic succession during deposition of the different Tertiary formations. These presumed folding phases possibly mark the contacts between the different formations and that later phases of the progressive folding reoriented the earlier folds by rotation into the same geometry of the later folds. This is particularly viable if the successive folding phases are not very different in their orientation. Thus the finite form of the folds would become similar in all parts of the Tertiary stratigraphic succession of Sinjar Anticline, hence the total coincidence of the pi-diagrams of the folds in theTertiary formations.

The present authors find the first possibility of paroxysmal folding in the Pliocene as more tenable since there is no angular unconformity or disconformity between the Tertiary formations. There are no substantial aggradational or degradational surfaces that would be marked by conglomeratic

deposition or surfaces of erosion at the contacts between the different Tertiary formations in Sinjar Anticline. Such contacts would imply substantial topography brought about by folding. It is appreciated however that a certain degree of vertical movements must have taken place in Sinjar area to accommodate the deposition of the Tertiary stratigraphic succession. The intensity of these movements was at times enough to cause intraformationl breccias and other facies changes, but there is no evidence that they caused any substantial folding.

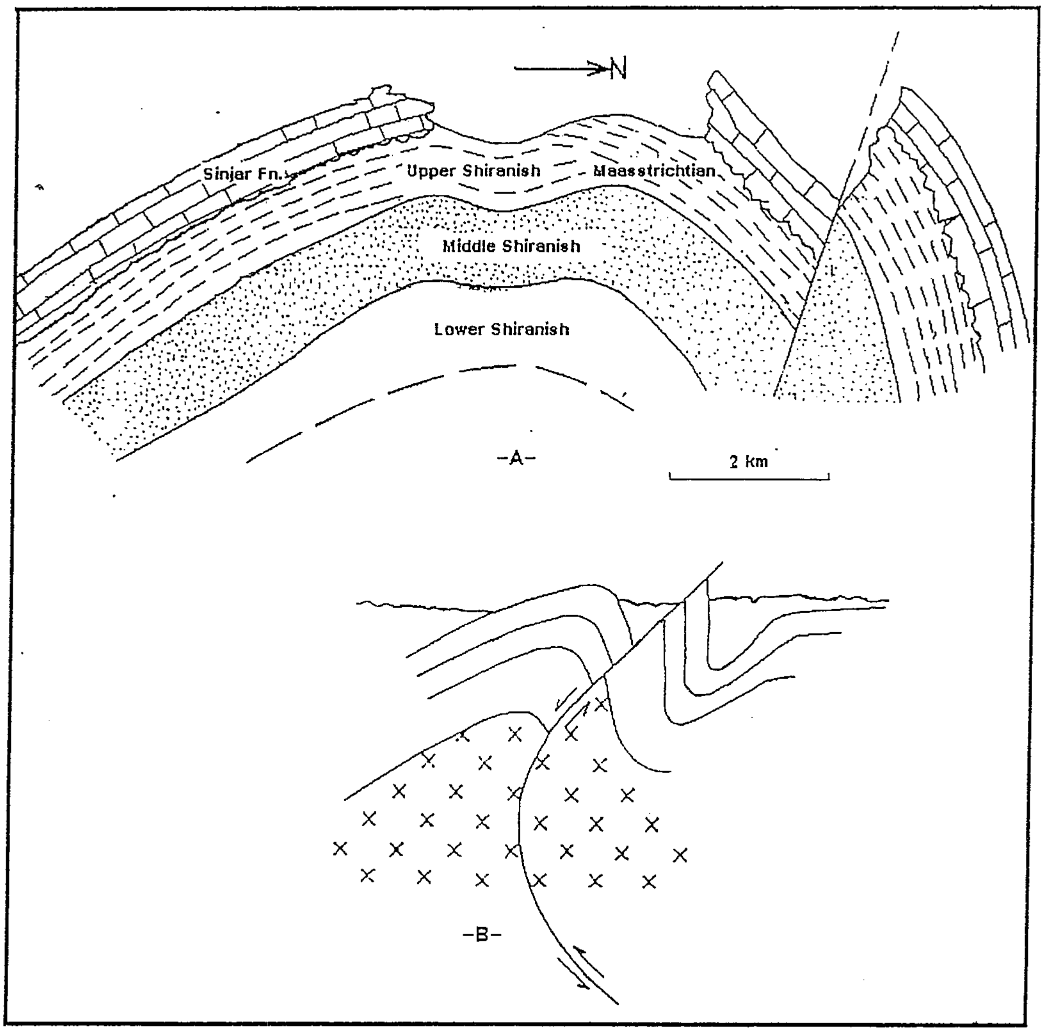


Fig.6: A –Normal fault at the northern limb of Sinjar Anticline
B- Schematic model of the listric fault beneath the anticline

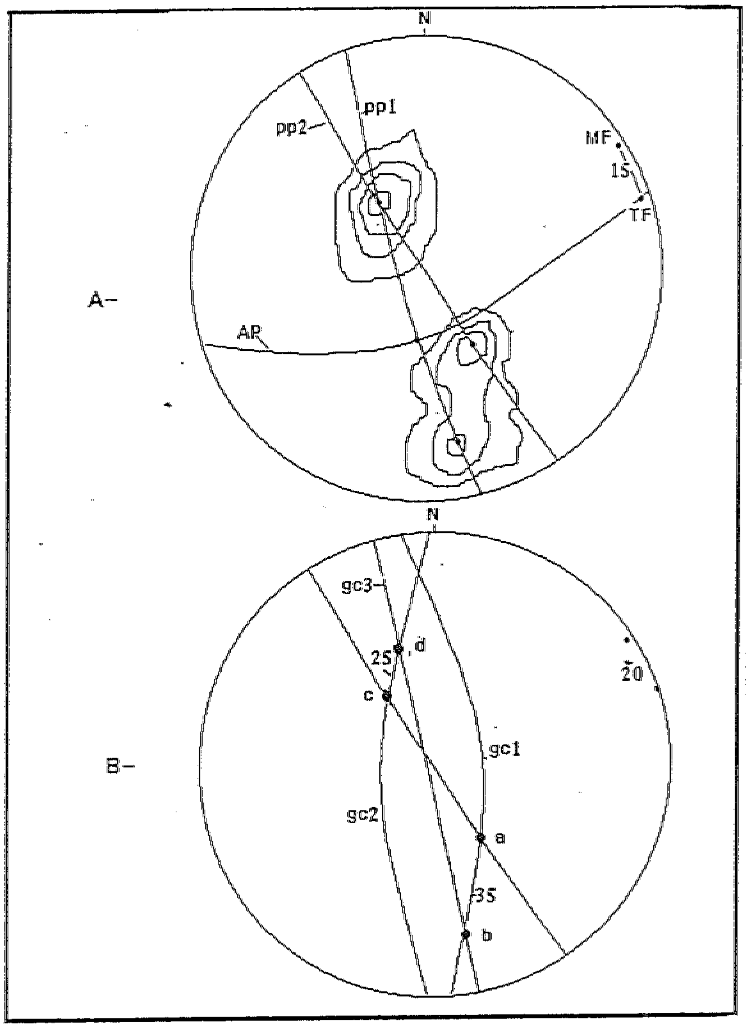


Fig.7: A-diagrams of Shiranish Formation
B-Extrapolation of the attitude of unexposed

CONCLUSIONS

1- Two distinctive Alpine folding phases are recognized in the NEE-SWW trending Sinjar Anticline; they are the Late Maastrichtian folding phase which was due to a passive orogeny that stemmed from strike-slip displacement along earlier listric normal fault, and a Pliocene paroxysmal folding phase brought about by a compressional orogeny stemming from dip-slip reverse displacements along the earlier listric faults. There is 20 degrees directional difference between fold axes belong to the Late Maastrichtian and Tertiary phases folding.

2- Geometrical analysis of the pi-diagram for folds in the different Tertiary formations in the Sinjar Anticline together with evidence from Tertiary stratigraphic record indicate that Tertiary folding took place as a paroxysmal phase in the Pliocene rather than progressive folding of Tertiary succession during its deposition.

3- The role of basement blocks underneath the Sinjar Anticline is manifested clearly in the regional structure and stratigraphy of Sinjar Anticline. In particular the role of the three transversal blocks of Goulat, Sinjar and Jeribe, as well as rejuvenation of displacements along the early longitudinal listric normal faults.

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