The Triassic of Aghdarband (AqDarband), NE-Iran, and its Pre-Triassic Frame				Editor: Anton W. Ruttner
Abh. Geol. B.-A.	ISSN 0378-0864 ISBN 3-900312-74-5	Band **38**	S. 7–79	Wien, April 1991

Geology of the Aghdarband Area (Kopet Dagh, NE-Iran)

By ANTON W. RUTTNER
With Contributions of RAINER BRANDNER & ELISABETH KIRCHNER*)

With 54 Text-Figures, 22 Diagrams, 1 Table and 4 Plates

NE-Iran
Kopet Dagh
Aghdarband
Upper Devonian
Lower Carboniferous
Triassic
Aghdarband Group
Qara Gheitan Formation
Sefid Kuh Limestone Formation
Nazarkardeh Formation
Sina Volcanic Formation
Miankuhi Formation
Ghal'eh Qabri Shales
Anabeh Conglomerate
Faqir Marl Bed
Aghdarband Coal Bed
Eo-Cimmerian Structure
Side-Slip Faults
Thrust Faults

Contents

*) Authors' addresses: Dr. ANTON W. RUTTNER, Geologische Bundesanstalt, Rasumofskygasse 23, P.O. Box 154, A-1031 Wien, Austria; Univ.-Prof. Dr. RAINER BRANDNER, Institut für Geologie und Paläontologie, Universität Innsbruck, Innrain 52, A-6020 Innsbruck, Austria; Univ.-Prof. Dr. ELISABETH KIRCHNER, Institut für Geowissenschaften, Universität Salzburg, Hellbrunnerstraße 34, A-5020 Salzburg, Austria.

Kurzfassung

Etwa 100 Kilometer ostsüdöstlich von Mashhad, der Hauptstadt der persischen Provinz Khorasan, ist in einer flachen Aufwölbung der Jura-Kreide-Schichtfolgen des östlichen Kopet Dagh das prae-jurassische Grundgebirge dieses etwa 700 km langen Gebirgszuges freigelegt. Das Erosionsfenster von Aghdarband hat eine Ausdehnung von etwa 15×20 Kilometer; nahe seiner nördlichen Begrenzung befindet sich der kleine Kohlenbergbau Aghdarband, der den Anstoß für ein umfassendes, jetzt endlich abgeschlossenes Forschungsprogramm gab.

Schon im Jahre 1956 erkannte der Schweizer Geologe K.T. GOLDSCHMID, der um eine geologische Beurteilung des Kohlenvorkommens gebeten worden war, daß es sich erstens um Kohlen triassischen Alters handelt und daß, zweitens, die stark gefalteten Trias-Schichten diskordant von einer flach gelagerten Jura-Schichtfolge überlagert werden, für die er den Namen Kashafrud-Formation vorschlug. Ein Versuch des gegenwärtigen Verfassers, im selben Jahr den komplizierten geologischen Bau des Gebietes aufzulösen, scheiterte an den damals vorhandenen unzulänglichen topographischen Unterlagen.

20 Jahre später standen dem Verfasser ausgezeichnete topographische Karten im Maßstab 1 : 5.000 zur Verfügung. Das Ergebnis einer intensiven Feldarbeit der Jahre 1975 und 1976 ist eine detaillierte geologische Karte, die, im Jahre 1984 gedruckt, als farbige Karte i. M. 1 : 12.500 dieser Arbeit beiliegt (Beilage 1). Die Legende für diese Karte hat mittlerweile einige Änderungen erfahren. Die jetzt gültige Legende ist der Beilage 3 (geologische Konturenkarte, tektonische Diagramme und Quer-Profile) zu entnehmen.

Die anläßlich der Kartierung gesammelten Gesteinsproben und Fossilien fanden in Wien, Innsbruck, Lausanne, Genf, Utrecht und Prag durch Spezialisten ihre Bearbeitung. Stratigraphische Profile wurden in der Trias von Aghdarband durch A. BAUD (Lausanne) im Jahre 1972 und R. BRANDNER (Innsbruck) im Jahre 1977 aufgenommen. Die Ergebnisse aller dieser geologischen, paläontologischen, sedimentologischen und stratigraphischen Bearbeitungen werden nunmehr in der Form einer Monographie vorgelegt. In diese Monographie konnten jetzt auch noch die neuesten sehr wichtigen Erkenntnisse aufgenommen werden, die ein Iranisches Geologen-Team im Laufe der Kartierungsarbeiten für das Quadrangle-Blatt Torbat-e-Jam gewonnen hat.

Die vorliegende Arbeit ist eine Dokumentation des heutigen geologischen Wissensstandes über das Gebiet des Erosionsfensters von Aghdarband, und damit die Dokumentation über einen, wenn auch kleinen Abschnitt des „Cimmerian Indosinian Foldbelt" (STÖCKLIN, 1980, 1983) bzw. der „Kimmmeriden" (SENGÖR, 1985), der durch spätere tektonische Ereignisse kaum mehr beeinflußt wurde.

Das Erosionsfenster von Aghdarband (vgl. Fig. 1) wird durch eine Störungslinie von wahrscheinlich regionaler Bedeutung, der Shatutak Fault, in zwei geologisch verschiedenartige Areale geteilt. Die Trias von Aghdarband befindet sich im nördlichen Teil des Fensters; sie wird sowohl im Norden wie im Süden von Störungen wahrscheinlich ebenfalls größeren Ausmaßes begrenzt. Die WNW–ESE-streichende „Northern Main Fault" ist eine linksseitige Blattverschiebung, welche die Trias-Gesteine von seinem schwach metamorphen nördlichen Rahmen trennt. Die „Southern Main Fault" dagegen ist eine Überschiebung; schwach metamorphe klastische Gesteine des südlichen Rahmens sind hier von SSW auf die nicht metamorphen Trias-Gesteine aufgeschoben.

Im großen gesehen hat der innere Bau des Trias-Vorkommens die Struktur einer WNW–ESE-streichenden Synklinale (Aghdarband- Synklinale). Im einzelnen sind drei tektonische Einheiten zu unterscheiden: ein schmaler Streifen steilgestellter Schichten entlang der Northern Main Fault (Slice I), von ihm durch eine vertikale Störung getrennt eine breite zentrale Synklinale, die im westlichen Teil des Gebietes von einer schmalen nördlichen Antiklinale begleitet wird (Slice II), und, östlich der Bergbau-Siedlung Aghdarband, eine Schuppe (Slice III), die von SSW der zentralen Synklinale aufgeschoben erscheint; die zentrale Synklinale (Slice II) ist dort stark eingeengt und in mehrere Teil-Synklinalen zerlegt. Die Fazies von Slice III unterscheidet sich etwas von jener der Slices I und II.

Die paläozoische Schichtfolge des nördlichen Rahmens besteht aus

1) einem dunkelgrauen cm-geschichteten Kalk mit zwischengeschaltetem vulkanischen Sandstein und Conodonten des Frasnian/Famennian (H. P. SCHÖNLAUB; B. HAMDI in EFTEKHARNEZHAD & BEHROOZI),
2) einer dunkelgrün gefärbten, sehr harten Gesteinsfolge, die im wesentlichen aus vulkanoklastischen Gesteinen (Brekzien, Mikrobrekzien, Sandstein, „Kristall-Brei"), Schiefer und sauren (andesitischen bis dacitischen) Gängen besteht (E. KIRCHNER in RUTTNER), mit einer Kalkbank des Famennian (SCHÖNLAUB) im Hangenden
und
3) einem kristallinen Kalk („Marmor"), der eine Mikrofauna des Unter-Karbons (Tournaisian) geliefert hat (B. HAMDI in EFTEKHARNEZHAD & BEHROOZI). Ein Konglomerat an der Basis dieses Kalkes führt Gerölle mit einer ober-devonen/unter-karbonen Mikrofauna (HAMDI).

Die iranischen Kollegen vergleichen diese Schichtfolge mit der gleichaltrigen des zentralen Alborz- Gebirges (Geirud-Formation, Mobarak-Kalk), der Verfasser dagegen mit sehr ähnlichen gleichaltrigen Schichtfolgen der südlichen Turan Platte, wie sie z. B. von der parautochthonen Kaukasischen Forerange beschrieben sind.

In dem von SSW auf die Trias überschobenen südlichen Rahmen konnten im kartierten Bereich 5 Schuppen unterschieden werden; sie bestehen aus violett-rotem oder grünlich-grauem quarzitischem Sandstein und violett-roten oder grünen serizitischen Schiefern; lokal enthält der Sandstein einzelne Konglomerat-Lagen. Die tiefste Schuppe, welche den Trias-Gesteinen unmittelbar aufliegt, ist ein tektonisches Gemisch, bestehend aus diesen schwach metamorphen Gesteinen und nicht metamorphen triassischen Gesteinen. Östlich des kartierten Gebiets – nahe dem östlichen Rand des

Fensters – enthält diese unterste Schuppe große Gesteins-Körper, bestehend aus Trias-Kalk und kristallinem (?Trias- oder ?Karbon-)Kalk (EFTEKHARNEZHAD & BEHROOZI). Der Verfasser vergleicht die bunten schwach metamorphen Gesteine des südlichen Rahmens mit ähnlichen – dort allerdings nicht metamorphen – oberkarbonen bzw. permischen Schichtfolgen des Kaukasischen Vorlandes und sieht in ihnen den überkippten, verschuppten und auf die Trias geschobenen Süd-Flügel der Aghdarband-Synklinale.

Gegen Süden werden die Gesteine des südlichen Rahmens durch die schon erwähnte Shahtutak Fault von bräunlich-roten, zum Teil auch grünlichen nicht metamorphen Schiefertonen, Sandsteinen und Konglomeraten getrennt, die nahezu die ganze südliche Hälfte des Erosionsfensters einnehmen. Unter den gut gerundeten Komponenten der Konglomerat-Lagen fallen Gerölle auf, die aus rosa-rotem Granit bestehen. Im südlichen Teil des Fensters wurde in Kalkgeröllen eine karbone, und in einem Falle, eine spät-permische Mikrofauna gefunden (EFTEKHARNEZHAD & BEHROOZI). In der südwestlichen Ecke des Fensters fanden diese beiden Autoren nicht nur einen normalen Transgressions-Kontakt dieser klastischen Gesteine mit den sehr wahrscheinlich permischen Ophioliten von Darreh Anjir, sondern auch aufgearbeitete ultrabasische Gesteine und Radiolarit-Gerölle in den basalen Konglomeraten dieser mächtigen klastischen Gesteinsfolge.

Im nördlichen Teil des Erosionsfensters unterlagert die gleiche Gesteinsfolge den ober-skythischen Sefid Kuh-Kalk. Der Kontakt ist am nordwestlichen Fuß des Sefid Kuh aufgeschlossen; eine nahe gelegene kleine Siedlung gab dieser somit unter-skythischen klastischen Schichtfolge den inoffiziellen Namen Qara Gheitan-Formation. Der Verfasser vergleicht diese Formation mit dem oberen (triassischen) Teil der „Herzynischen Molasse" der russischen Autoren. EFTEKHARNEZHAD & BEHROOZI rechnen auch die schwach metamorphen Gesteine des südlichen Rahmens der Trias zur Qara Gheitan-Formation.

Die Shatutak Fault ist wahrscheinlich das wichtigste Strukturelement des Alt-Kimmerischen Orogens soweit dieses im Erosionsfenster von Aghdarband sichtbar ist. A. BEHROOZI fand entlang dieser großen Störung langgestreckte Gesteinskörper, die mit den entsprechenden paläozoischen Gesteinen des nördlichen Rahmens der Trias verglichen, z.T. aber auch der Trias zugerechnet werden können; als einziges Strukturelement des Erosionsfensters hat diese Störung auch noch die jurassischen Deckschichten des Fensters erfaßt. Ähnlich wie bei der Northern Main Fault handelt es sich sehr wahrscheinlich auch bei der Shatutak Fault um eine Blattverschiebung, deren Richtung und Ausmaß in diesem Falle aber nicht bekannt ist. Hinsichtlich der räumlichen Beziehung zwischen dem nördlichen und südlichen Teil des Fensters von Aghdarband zur Trias-Zeit sind wir daher noch völlig im dunkeln.

Heute bezeichnet die Shahtutak Fault auf der Erdoberfläche den Südrand der Turan Platte. Etwa 60 Kilometer südwestlich dieser Störung – 40 Kilometer südwestlich des südlichen Fenster-Randes – kommt unter der Jura-Bedeckung in Form des kürzlich (1985/88) von EFTEKHARNEZHAD & BEHROOZI entdeckten Ophiolith-Gürtels Fariman – Torbat-e-Jam ein alter Ozeanboden zum Vorschein, dessen permisches Alter nicht nur für die eingelagerten Kalk-Blöcke (F. BOZORGNIA in EFTEKHARNEZHAD & BEHROOZI) sondern jetzt auch für ein zweifellos ozeanisches Sedimentgestein (H. KOZUR & H. MOSTLER) sichergestellt ist. Die in der SW-Ecke des Erosionsfensters von Aghdarband zutage tretenden Ophiolithe von Darreh Anjir enthalten ebenfalls Kalkblöcke permischen Alters (F. KASHANI & F. BOZORGNIA in EFTEKHARNEZHAD & BEHROOZI); sie sind sehr wahrscheinlich mit dem Ophiolith-Gürtel Fariman – Torbat-e-Jam unter der Jura-Bedeckung zu verbinden und könnten wegen ihres vorwiegend Mélange-Charakters als dessen nördlichster, auf den Südrand der Turan-Platte obduzierter Teil aufgefaßt werden. Der tatsächliche Südrand dieser Platte würde sich dann heute südlich der Shahtutak Fault befinden.

Die mächtige klastische und bunt gefärbte Untertrias-Schichtfolge der Qara Gheitan-Formation liegt im Süden transgressiv auf den Ophiolithen von Darreh Anjir, im Norden aber nach Meinung des Verfassers ursprünglich auf älteren Gliedern der „Herzynischen Molasse", die ihrerseits der Herzynischen Turan-Platte aufliegen. Man könnte sich also die Qara Gheitan-Formation als Teil eines riesigen Schuttfächers vorstellen, der sich von einem nördlichen Herzynischen Orogen in früh-triassischer Zeit gegen Süden über den südlichen Schelf Laurasiens entweder in einen schon im Perm vorhandenen ozeanischen Trog oder auf die Obduktions-Produkte eines solchen Troges ergoß. Nach R. BRANDNER könnte die etwa gleichaltrige Sorkh Shale-Formation Zentral-Irans ein sehr distales Äquivalent dieses Schuttstromes sein.

Im nördlichen Teil des Erosionsfensters ist die Qara Gheitan-Formation die sedimentäre Unterlage für die Trias von Aghdarband, deren vier Formationen zur Aghdarband Group zusammengefaßt sind. Die triassische „Sea of Aghdarband" befand sich somit nach den Vorstellungen des Verfassers auf einem randlichen (südlichen) Bereich der herzynischen Turan-Platte.

Die Sefid Kuh limestone Formation ist gekennzeichnet durch eine Wechsellagerung eines Meter-gebankten bis massiven gelblichen Kalkes mit einem grauen oder blaugrauen Zentimeter- bis Dezimeter-geschichteten Kalk; der letztere ist z. T. knollig und häufig mit Grabgängen durchzogen. Lagen eines kreuzgeschichteten Kalk-Arenites unterstreichen den Seichtwasser-Charakter des Kalkes, der im Typ-Profil, gemessen von A. BAUD und R. BRANDNER am westlichen Steilhang des Sefid Kuh, 200 m mächtig ist. Der Kalk wird von diesen beiden Autoren als Produkt eines Transgressions-Regressions-Zyklusses aufgefaßt, hervorgerufen durch eustatische Seespiegel-Schwankungen der Tethys. Auf Grund der aus dem Kalk gewonnenen Conodonten wurde von D. DONOFRIO ein spät-skythisches Alter (Spathian) des Kalkes festgestellt.

Eine etwa 15 m mächtige Lage, bestehend aus vulkanoklastischem Konglomerat und grobem Sandstein, ist im Typ-Profil an der Basis des Kalkes aufgeschlossen; sie ist durch einen raschen Übergang mit dem überlagernden Kalk-Arenit verbunden und wird daher in die Sefid Kuh limestone Formation mit einbezogen. Die Art des Kontaktes dieser vulkanoklastischen Lage mit dem darunter liegenden roten Konglomerat und Sandstein der Qara Gheitan-Formation, dagegen, ist umstritten. Der Verfasser, und mit ihm J. STÖCKLIN und A. BAUD, sehen eine schwache Winkeldiskordanz zwischen den beiden Formationen; dies wird von EFTEKHARNEZHAD, BEHROOZI und BRANDNER in Abrede gestellt. Der letztgenannte Autor verbindet den Sefid Kuh-Kalk mit der Qara Gheitan-Formation und betrachtet ihn zusammen mit der hangenden neu aufgestellten Nazarkardeh-Formation als das Endglied der Herzynischen Molasse.

Der Berg Sefid Kuh und damit auch das Typ-Profil der Sefid Kuh limestone Formation befindet sich westlich außerhalb des vom Verfasser kartierten Bergbau-Gebietes. Innerhalb dieses Gebietes findet man diesen Kalk nur in Form von langgestreckten, tektonisch begrenzten Gesteinskörpern.

Die neu aufgestellte unter-anisische Nazarkardeh-Formation umfaßt einen dünn geschichteten Hornsteinkalk, der den Sefid Kuh-Kalk in dessen Typ-Profil überlagert, und eine Ammoniten- führende Schichtfolge, die aus einer Wechsellagerung von Knollenkalk, tuffitischem Mergel, Schieferton und Sandstein besteht; diese letztere Schichtfolge steht am Osthang des Sefid Kuh an und wurde im kartierten Gebiet als „Fossilhorizont 1" ausgeschieden. Der Name stammt vom Kuh-e-Nazarkadeh, einem beherrschenden Aussichtsberg etwa 1,5 km WNW der Bergbausiedlung Aghdarband gelegen, an dessen Südwest-Flanke die Formation gut sichtbar ist.

Das Alter des Hornstein-Kalkes ist Aegean/Bithynian auf Grund der Conodonten (D. DONOFRIO), das des „Fossilhorizontes 1" Bithynian auf Grund der Ammoniten (L. KRYSTYN & F. TATZREITER). In letzterem wurden von den beiden Autoren zwei Ammoniten-Horizonte festgestellt: die obere Ismidicus-Zone mit *Aghdarbandites ismidicus* n. g. (früher *Anagymnotoceras ismidicum*) und die untere Osmani-Zone mit *Nicomedites osmani*. Bemerkenswerterweise wurden Fossilien der Osmani-Zone nur in den tektonische Einheiten Slice I und Slice II, und Fossilien der Ismidicus-Zone nur in der von Süden aufgeschobenen Einheit Slice III gefunden.

Zusammengenommen charakterisiert die „Nicomedites Assoziation" (KRYSTYN & TATZREITER) beider Ammoniten-Horizonte faunistisch die biogeographische unter-anisische Nord-Tethys- Subprovinz, deren Fauna sich von der gleichaltrigen Fauna der Süd-Tethys-Subprovinz (oder der Tethys-Provinz s. st.) eindeutig unterscheidet und die sich in einem schmalen Streifen von Gebze (SE Istanbul) entlang des Südrandes von triassisch Laurasien über eine Entfernung von 5000 Kilometern bis Qilian Shan (Nord-China) verfolgen läßt; sie wurde am Ostrand von Laurasien östlich des Okhotsken Meeres wieder gefunden. KRYSTYN befürwortet die Annahme einer natürlichen Barriere gegenüber rein klimatischen Ursachen für die Erklärung dieser auffallenden faunistischen Differenzierung.

Eine 400–700 Meter mächtige vulkanogene Schichtfolge überlagert die Sefid Kuh- bzw. die Nazarkardeh-Formation. Sie besteht vorwiegend aus tuffitischem Sandstein und Schieferton, mit Zwischenlagen von tuffitischem Mergel und Kalk; einige wenige Konglomerat-Lagen sind auch zwischengeschaltet. Sohlmarken und gradierte Schichtung verleihen manchen Sandstein-Schichten ein flyschartiges Aussehen. Diese Schichtfolge wurde nach dem Hauptstollen des östlichen Kohlenfeldes von Aghdarband Sina volcanic Formation genannt.

Nach A. BAUD, G. STAMPFLI, D. STEEN, R. CAS und H. SARP deuten sowohl die eingeschlossenen Gesteinsbrocken wie die mineralische Zusammensetzung des Sandsteines auf einen intermediären (andesitischen und trachyandesitischen) bis sauren (trachydazitischen, sogar rhyolitischen) Vulkanismus im Herkunftsgebiet dieser vulkanogenen Sedimente hin. Eine allgemeine Tendenz einer nach oben zunehmenden Azidität kann innerhalb der Formation beobachtet werden. BAUD und STAMPFLI sind der Meinung, daß die vulkanoklastischen Sedimente in einem Backarc-(Rand-)Becken zur Ablagerung kamen, das sich nördlich einer angenommenen Subduktionszone befand.

Zwei lithologische Einheiten (Members) der Sina-Formation können unterschieden werden: das tiefere tuffaceous Sandstone Member und das höhere tuffaceous Shale Member. Das fossilführende Faqir Marl Bed („Fossil-Horizont 2") wird als tiefste Schicht des Shale Members betrachtet.

Eine zuverlässige Altersbestimmung war nur für das obere Shale Member möglich: die Ammoniten-(*Romanites*-)Fauna des basalen Faquir Marl Bed ist nach L. KRYSTYN und F. TATZREITER spät-ladinisch (Longobard), Radiolarien und Schwamm-Nadeln in einer kieseligen Kalkbank im äußersten Hangenden des Shale Members weisen auf ein früh-karnisches Alter (D. DONOFRIO). Das Shale Member der Sina-Formation umfaßt somit den Zeitraum Spätestes Ladin – Frühes Karn.

Nicht so gut bekannt ist die geologische Zeitspanne für das tiefere Sandstone Member. Funde von *Daonella lommeli* in dem Sandstein unterhalb des Faqir Marl Bed machen es wahrscheinlich, daß zumindest der obere Teil des Sandstone Members noch spät-ladinischen Alters ist. Bezüglich der basalen Schichtfolge des Members besaßen wir bis vor kurzem nur negative Altershinweise; es waren darin weder ober-anisische noch unter-ladinische Leitfossilien gefunden worden. Es war daher naheliegend, das Vorhandensein einer beträchtlichen Schichtlücke zwischen der unter-anisischen Nazarkardeh-Formation und der im wesentlichen ober-ladinischen Sina-Formation zu vermuten.

Für das Vorhandensein einer solchen Schichtlücke schien ein Konglomerat zu sprechen, das sowohl im Westen des engeren Gebietes von Aghdarband (Schlucht des Kal-e-Faqir-Tales östlich des Sefid Kuh, Slice II) wie im Osten (Osthang des Kale-e-Anabeh-Tales, Slice III) an der Basis der Sina-Formation ansteht. Die wohl-gerundeten, aber unsortierten Gerölle dieses Basal-Konglomerates der Sina-Formation können einen Durchmesser von 10 Zentimetern erreichen; sie bestehen ausschließlich aus Sefid Kuh-Kalk. Das Konglomerat liegt sowohl auf Schichten der Nazarkardeh-Formation wie auf Sefid Kuh-Kalk. Dies spricht für eine Erosions-Phase vor Ablagerung der vulkanischen Sedimente der Sina-Formation. Eine solche Erosions-Phase wäre auch eine plausible Erklärung für das sporadische Auftreten der Nazarkardeh-Formation in dem kartierten Gebiet von Aghdarband.

Andererseits liegt am Südwesthang des Kuh-e-Nazarkardeh – westlich der Bergbau-Siedlung Aghdarband – eine Verzahnung der Nazarkardeh-Formation mit dem Sefid Kuh-Kalk und ein Übergang der ersteren in die Sina-Formation vor. Deshalb wurde seinerzeit (1983, 1984) und auch noch in der Legende zu der geologischen Karte (Beilage 1), die Nazarkardeh-Formation „Transition Beds" genannt. Die oben erwähnte Schichtlücke wird neuerdings auch durch Conodonten in Frage gestellt, die in Proben aus „stratigraphic section No. 10" (östlich des Ortes Aghdarband, Fig. 12a) gefunden wurden und nach D. DONOFRIO auf ein ober-anisisches bis unter-ladinisches Alter basaler Teile des Sandstone Members hinweisen. Wahrscheinlich war die genannte Erosionsphase sowohl zeitlich wie räumlich beschränkt und Folge einer gewissen tektonischen Unruhe, welche mit der beginnenden vulkanischen Aktivität einherging.

Das meist grünlich gefärbte Sandstein-Member der Sina-Formation enthält häufig Pflanzenreste, meist solche von *Equisetum* sp. Diese zum Teil bis arm-dicken Schachtelhalm-Stämme sind wahrscheinlich in Trübungsströmen von nicht zu weit entfernten Küsten zum Ort ihrer Ablagerung verfrachtet worden. Dasselbe gilt für Oosporen von Charophyten, die R. OBERHAUSER in einer Probe fand, welche einer violett-roten tonigen Zwischenlage des Sandstone Members am Westhang des Kal-e-Anabeh-Tales (Slice III) entnommen worden war.

Profile durch das Member wurden von A. BAUD und R. BRANDNER gemessen und im Detail beschrieben. Eine auffallende Schichte eines harten vulkanischen Sandsteines bildet den hangenden Abschluß des Sandstone Members.

Von besonderem Interesse ist eine zwischengeschaltete, etwa 15 Meter mächtige Bank, die aus einem polymikten Konglomerat und grobem Sandstein besteht; sie ist als kartierbare Schicht des Sandstone Member auf die tektonische Schuppe Slice III des östlichen Aghdarband- Gebietes beschränkt und wurde nach dem Kal-e-Anabeh-Tal Anabeh Conglomerate genannt. Unter den walnuß- bis faustgroßen Komponenten des Konglomerates (metamorphe und vulkanische Gesteine, Hornstein, Quarz, weißer Quarzit) fand A. BAUD Kalkgerölle, deren Mikrofauna auf Kalke des Mittel-Karbons, des späten und spätesten Perm und der frühen Trias im Ursprungsgebiet hinweist. Aus der Tatsache, daß das Anabeh-Konglomerat auf die tektonische Schuppe Slice III beschränkt ist, kann geschlossen werden, daß dessen Ursprungsgebiet südlich der Ladinischen „Aghdarband-See" gelegen war. Der Verfasser (1983, 1984) verglich dieses Konglomerat mit der Baqoroq-Formation von Nakhlak.

Die Hauptfarbe des Shale Member im Gelände ist dunkelgrün bis grünlich-grau. Der Schieferton zerfällt an der Oberfläche zu dünnen Bleistift-förmigen Fragmenten („pencilshales"). Zwischengelagert sind Schichten, bestehend aus dünn-geschichtetem feinkörnigem Sandstein, sowie fossilführende kalkige Lagen; der Sandstein zeigt deutliche Merkmale eines Turbidites. Die Basis-Schicht des Members ist das Faqir Marl Bed, das hangendste Schichtglied ist wieder ein harter, dunkelgrüner vulkanischer Sandstein. Die geschätzte Mächtigkeit des Shale Members ist 300–500 Meter.

Das basale Faqir Marl Bed (= „Fossil-Horizont 2") ist in dreierlei Hinsicht bemerkenswert:

- Es fällt in der Landschaft durch seine rosarote und hellgrüne Farbe auf.
- Dadurch ist es ein wichtiger Leithorizont für die Kartierung.
- Es enthält eine Vielfalt von Fossilien: Cephalopoden, Brachiopoden, Pelecypoden und Crinoiden ebenso wie Foraminiferen und Ostracoden.

Der Name kommt von dem Kal-e-Faqir-Tal, wo das Bed gut aufgeschlossen ist. Lithologisch besteht es aus Schieferton, Mergel, tuffitischem Mergel und tuffitischem, kalkigem Sandstein.

Die Ammoniten-Fauna des Faqir Marl Beds ist auffallend einheitlich in dem ganzen kartierten Gebiet. Sie ist gekennzeichnet durch die Dominanz der Gattung *Romanites* und wird daher von L. KRYSTYN und F. TATZREITER „*Romanites*-Fauna" genannt. Nach diesen beiden Autoren verkörpert sie hier die *Frankites regoledosus*-Zone des obersten Ladin (Longobard 3). Im Gegensatz zu der unter-anisischen Ammonitenfauna der Nazarkardeh-Formation („Fossil-Horizont 1") handelt es sich bei der ober-ladinischen *Romanites*-Fauna des Faqir Marl Beds („Fossilhorizont 2") um eine tropische Tiergesellschaft, die für die gesamte Tethys charakteristisch ist. Das gleiche gilt auch für die Schwebe-Crinoiden, die Holothurien und Ostracoden (E. KRISTAN-TOLLMANN) und für die Foraminiferen (R. OBERHAUSER). Abgesehen von den Ammoniten ist das Faqir Marl Bed durch große Nautiloideen, Stielglieder von *Traumotocrinus caudex* (KRISTAN-TOLLMANN) und durch massenhaftes Auftreten des Brachiopoden *Tethyspira* n. gen. *persis* n. sp. (M. SIBLÍK) gekennzeichnet.

Dem Shale Member zwischengelagerte Schichten von feinkörnigem, dünn-schichtigem, tuffitischem Sandstein zeigen Fließ- und Rippelmarken sowie unbestimmbare Pflanzenreste auf ihren Schichtflächen. Nach A. BAUD weisen diese Turbidite zusammen mit dünn geschichteten Mergel-Zwischenlagen, welche pelagische Bivalven, Schwamm-Nadeln und isolierte Crinoiden-Stielglieder enthalten, auf ein distales „deep ramp environment" hin.

Funde von *Daonella lommeli* nahe unterhalb der erwähnten hangenden Sandsteinbank weisen darauf hin, daß der größte Teil des Shale Members noch spätest-ladinischen Alters ist. Das Hangendste des Members ist aber früh-karnisch. Dies ist bewiesen durch eine Probe von einer etwa 80 cm mächtigen Bank kieseligen Kalkes, die auf einem Rücken ESE der Bergbau-Siedlung Aghdarband unmittelbar unter dem Aghdarband Coal Bed ansteht. Eine reiche Vergesellschaftung von Radiolarien und Schwamm-Nadeln weist nach D. DONOFRIO auf spätes Cordevol.

Das „Aghdarband Coal Bed" ist das tiefste Schichtglied der Miankuhi-Formation, die im übrigen aus einer monotonen Folge von braunem Schieferton und einigen wenigen eingelagerten Schichten von dünnschichtigem Siltstein und feinkörnigem Sandstein besteht. Die Formation bildet den Kern der Aghdarband-Synklinale; sie ist nach dem Miankuhi-Gelände („Zwischen den Bergen") westlich der Bergbau-Siedlung benannt.

Das im allgemeinen etwa ein Meter mächtige Kohlenflöz ist autochthon; es wird von einem Wurzelboden unterlagert, der entweder aus kohligem Schieferton oder aus gebleichtem tuffitischem Sandstein besteht. Das Hangende des Flözes sind dunkelgraue pflanzenführende Schiefertone, die nach oben in einen dickbankigen, nicht tuffitischen Quarzsandstein übergehen. Dieser meist etwa 5 m mächtige „Hangendsandstein" enthält ebenfalls Pflanzenreste; er geht nach oben durch Wechsellagerung in die braunen Schiefertone der Miankuhi-Formation über.

Die Pflanzenreste der Hangendschichten des Kohlenflözes deuten nach M. BOERSMA und J.H.A. VAN KONIJENBURG-VAN CITTERT mit großer Wahrscheinlichkeit auf ein norisches Alter hin. Folglich muß eine beträchtliche Schichtlücke zwischen der Sina-Formation und der Miankuhi-Formation angenommen werden, die das obere Karn und wahrscheinlich auch tiefere Teile des Nor umfaßt. Die vulkanische Sedimentation endete im frühen Karn, und eine neue Transgression begann mit der Bildung von Mooren wahrscheinlich erst im Nor.

Im westlichen Teil des kartierten Gebietes wird das Coal Bed von einem Konglomerat und einem groben, kreuzgeschichteten Sandstein unterlagert. Die gut gerundeten aber unsortierten Gerölle des Konglomerates, die Kopfgröße erreichen können, bestehen größtenteils aus aufgearbeitetem vulkanischem Material. Dies ist ebenfalls ein Hinweis auf ein rasches Verschwinden des Ladinischen Meeres im frühen Karn.

Abgesehen von den Pflanzenresten lieferte die Miankuhi-Formation keine anderen Mega-Fossilien, auch keine bestimmbaren Sporen oder Pollen. In Proben aus den Schiefertonen fand R. OBERHAUSER eine arme Sandschaler-Fauna, die keinerlei Aussagen bezüglich des Alters zuläßt. Es ist eine autochthone bentonische Foraminiferen-Fauna, die auf ein marines, aber sehr lebensfeindliches Milieu hinweist.

Die Schiefertone der Miankuhi-Formation sind die jüngsten Schichten, die noch von der alt-kimmerischen Orogenese erfaßt wurden.

Die alt-kimmerischen Strukturen werden diskordant von der Kashafrud-Formation überlagert, deren tieferer Teil im allgemeinen ein Konglomerat ist; marine Fossilien (Bajocian) erscheinen erst 170–200 Meter oberhalb der Basis der Formation.

In der Nähe des Dorfes Ghal'eh Qabri aber, etwa 11 Kilometer ostsüdöstlich der Bergbausiedlung Aghdarband, liegt auf den alt-kimmerischen Strukturen diskordant ein weißer Sandstein, der die Basis von schwarzen Schiefertonen bildet; die letzteren wurden vorläufig Ghal'eh Qabri Shales genannt. Der weiße Sandstein enthält neben Kohlen-Schmitzen Pflanzenreste. Diese Flora unterscheidet sich deutlich von jener des Aghdarband Coal Beds; sie wurde von M. BOERSMA und J.H.A. VAN KONIJENBURG-VAN CITTERT mit größter Wahrscheinlichkeit in das Rhät eingestuft.

Es ist noch nicht entschieden, ob die Ghal'eh Qabri Shales – und im besonderen der basale pflanzenführende Sandstein – als lokal entwickelte besondere Formation oder als basaler Teil der Kashafrud-Formation aufgefaßt werden soll. Wie dem auch sei, die alt-kimmerische Orogenese wird durch diese Flora in die Zeitspanne ?spätes Nor bis frühes Rhät festgelegt.

Eine schwache jung-alpidische (tertiäre) Orogenese hatte eine domartige Aufwölbung des Gebiets von Aghdarband zur Folge; damit war die Voraussetzung für die Entstehung des Erosionsfensters geschaffen. Nach Beseitigung der Deckschichten wurde die Landoberfläche zu einer Peneplain erodiert, die heute in der Hochfläche südlich von Aghdarband noch erhalten ist. Weite Teile dieser Hochfläche, aber auch deren Hänge gegen Norden und selbst tief liegende Gebiete östlich und westlich von Aghdarband, sind von Löß bedeckt; Löß-Ablagerung fand offensichtlich während langer Zeitspannen des Pleistozäns statt.

Nach einer langen Periode tektonischer Ruhe (?spätestes Tertiär–frühes Quartär), welche zu der Ausbildung der oben erwähnten Peneplain führte, begann eine neuerliche Hebung des Gebietes; sie leitete eine intensive Erosionstätigkeit des Kashaf Rud und dessen Seitengerinne ein. Diese Hebung ist heute noch aktiv; das Flußbett ist tief in ältere Alluvial-Terrassen eingeschnitten.

Schlußfolgerungen

❶ Der Verfasser ist nach wie vor der Ansicht, daß die Trias von Aghdarband auf südlichen Rand-Bereichen der Herzynischen Turan-Platte abgelagert wurde, oder, mit anderen Worten, daß die Triassische „Sea of Aghdarband" ein epikontinentales nördliches Randmeer der Tethys war. Er betrachtet die Ober-Devon- und Unter-Karbon-Gesteine, die im nördlichen Rahmen der Trias und entlang der südlichen Shahtutak Fault anstehen, als Teil dieser Platte, weil sie enge Beziehungen zu gleichaltrigen Gesteinen des kaukasischen Vorlandes aufweisen. Die Shahtutak Fault bezeichnet möglicherweise den heutigen Südrand der Turan-Platte.

❷ Die früh-skythische Qara Gheitan-Formation wird hier als oberer (triassischer Teil) der „Herzynischen Molasse" gedeutet; die schwach metamorphen roten und grünen klastischen Gesteine des südlichen Trias-Rahmens könnten zu tieferen Teilen dieser Molasse gehören. Es muß angenommen werden, daß diese klastischen Gesteine im Gebiet nördlich der Shahtutak Fault ursprünglich die herzynisch deformierten älteren paläozoischen Gesteine diskordant überlagert haben; im Süden dagegen liegt die Qara Gheitan-Formation nach EFTEKHARNEZHAD & BEHROOZI diskordant auf den wahrscheinlich permischen Ophiolithen von Darreh Anjir. Dies erweckt die Vorstellung eines riesigen früh-triassischen Schuttfächers, der sich vom Herzynischen Orogen gegen Süden über den südlichen Kontinentalrand entweder in einen ozeanischen Trog oder auf permisch obduzierte Teile eines solchen Troges ergoß. Ganz im Süden könnte nach R. BRANDNER die Sorkh Shale-Formation Zentral-Irans ein fernes Äquivalent der Qara Gheitan-Formation sein.

❸ Vier Formationen der Aghdarband-Gruppe repräsentieren die Ablagerungen der triassischen „Sea of Aghdarband", die durch ihre intermittierende Existenz und durch einen kräftigen Vulkanismus in ihrer Nachbarschaft gekennzeichnet war.

❹ Die triassische Schichtfolge ist unterbrochen durch eine zeitlich wie räumlich eingeschränkte Erosionsphase (wahrscheinlich im späten Anis) und eine länger andauernde Schichtlücke, welche das späte Karn und wahrscheinlich auch das frühe Nor umfaßt. Es können somit drei triassische Sedimentationsperioden unterschieden werden:

1) Ober-Skyth – Unter-Anis.
2) Ladin – Unter-Karn.
3) Ober-Nor – Unter-Rhät.

A. BAUD unterscheidet acht „Events" in der Geschichte der „Sea of Aghdarband"; Event Nr. 3 entspricht dem Ende der erste Sedimentationsperiode, Event Nr. 7 ungefähr dem Ende der zweiten und Event Nr. 8 dem Ende der dritten Sedimentationsperiode. R. BRANDNER dagegen zählt zur ersten Sedimentationsperiode auch die Qara Gheitan-Formation und betrachtet die Folge Qara Gheitan-Formation – Sefid Kuh Limestone Formation – Nazarkardeh-Formation als den oberen Teil der Herzynischen Molasse.

❺ Spuren von Vulkanismus wurden auch im oberen Skyth und im unteren Anis gefunden. Seinen Höhepunkt fand der intermediäre bis saure Vulkanismus aber im Ladin, um im frühen Karn zu enden. A. BAUD und G. STAMPFLI setzen ein „back-arc setting" der ladinischen „Sea of Aghdarband" voraus; der Verfasser fand jedoch keinerlei Anzeichen eines „back-arc rifting" in den triassischen Sedimentfolgen von Aghdarband.

❻ R. BRANDNER sieht im ober-skythischen Sefid Kuh-Kalk enge Beziehungen zu anderen gleichaltrigen Ablagerungen der Tethys, und L. KRYSTYN betont den pan-Tethys-Charakter der Ammoniten-Fauna des ober-ladinischen Faqir Marl Beds („Fossil-Horizont 2"), in Übereinstimmung mit E. KRISTAN-TOLLMANN bezüglich der Echinodermen und Ostracoden.

❼ Die unter-anisische „Nicomedites-Fauna" der Nazarkardeh-Formation dagegen ist nach L. KRYSTYN beschränkt auf einen schmalen Streifen, der den ganzen Südrand von triassisch Laurasien von der Türkei bis zum Pazifik umrahmt und von dem genannten Autor „Nord-Tethys-Provinz" benannt wird.

❽ Das Anabeh-Konglomerat im Sandstone Member der Sina-Formation ist auf die tektonische Schuppe Slice III beschränkt. Es muß daher südwestlich der ladinischen „Sea of Aghdarband" ein Festland gewesen sein, das entsprechend der Geröll-Zusammensetzung zum Teil aus metamorphen und vulkanischen Gesteinen, zum Teil aus Kalken des mittleren Karbons und des oberen Perm bestand (A. BAUD). Die Mikrofazies der Kalkgerölle des oberen Perm entspricht jener der oberen Nesen-Formation des Alborz-Gebirges, und die Mikrofazies der Kalkgerölle des obersten Perm scheint nach A. BAUD ein Äquivalent im zentralen Afghanistan (SW von Kabul) zu haben.

❾ Dicke Stengel von *Equisetum* sp. im Sandstone Member der Sina-Formation deuten ebenso auf die Nähe einer Küste während der zweiten Sedimentationsperiode hin wie Oosporen von Characeen in einer Schieferton-Zwischenlage dieses Members. Im späten Ladin wurde die „Sea of Aghdarband" immer tiefer; für das Shale Member der Sina-Formation wird von A. BAUD ein „distal deep ramp environment" angenommen. Umso bemerkenswerter ist das rasche Verschwinden des Meeres im untern Karn.

❿ Während der dritten Sedimentationsperiode war die „Sea of Aghdarband" ein isoliertes marines Becken; die in den Schiefertonen der Miankuhi-Formation gefundene benthonische Foraminiferen-Fauna deutet auf ein lebensfeindliches Milieu (R. OBERHAUSER).

⓫ Der tektonische Bau der Trias von Aghdarband ist das Ergebnis einer Kombination von Kompression (Faltung) und Seitenverschiebung. Die Faltenachsen sind als Folge der Seitenverschiebung oft steilgestellt. Eine Analyse dieser Steilstellung (Rotation der Faltenachsen) ergab für die Northern Main Fault eine linksseitige Verschiebung. Überschiebungen und Überkippungen von Falten verleihen dem tektonischen Bau ein alpinotypes Gepräge. Da jedoch das Ausmaß der Einengung bzw. der Seitenverschiebungen und bezüglich der großen Shahtutak Fault auch die Verschiebungs-Richtung nicht bekannt ist, befinden wir uns hinsichtlich der ehemaligen Lage einzelner Bauelemente zueinander noch völlig im dunkeln.

⓬ Die Zeitspanne für die alt-kimmerische Orogenese kann im Gebiet von Aghdarband auf das Intervall spätes Nor – frühes Rhät eingeengt werden.

⓭ Die vorliegenden Ergebnisse stehen in Einklang mit geodynamischen Modellen, die das Alborz-Gebirge und Zentral-Iran in der Trias-Zeit nicht zu weit entfernt vom Süd-Rand der Turan-Platte stellen. Aber auch im Paläozoikum scheint diese Entfernung nicht allzu groß gewesen zu sein. Die Gleichstellung der paläozoischen Gesteine des nördlichen Rahmens der Trias von Aghdarband mit jenen des Alborz-Gebirges durch EFTEKHARNEZHAD & BEHROOZI geschieht nicht ohne Grund, und K. WEDDIGE (1984) hat sehr eindrucksvoll den Einfluß der herzynischen Orogenese auf die Entwicklung des oberen Paläozoikums von Zentral-Iran dargestellt.

Danach befand sich während des Ober-Devons und Unter-Karbons auf dem nordöstlichen Zentral-Iran eine Mio-Geosynklinale, und deren Merkmale „reflect a position of the Iranian sea at the southern margin of the Turan Eugeosyncline". In Einklang damit steht die Feststellung H.P. SCHÖNLAUBS bezüglich des Ober-Devons von Aghdarband:

„Die Conodontengemeinschaft spiegelt ein küstenfernes pelagisches Milieu am Rande eines Kontinentes wider". Das Ober-Devon von Aghdarband nimmt somit eine Mittelstellung *zwischen dem Schelf-Meer von Zentral-Iran* und der Eugeosynklinale der Turan-Platte ein.

⓮ Der „Cimmerian Indosinian Foldbelt" bzw. die „Kimmeriden" können nur über einzelne von einander getrennte Bereiche durch das südliche Asien verfolgt werden (siehe z. B. J. STÖCKLIN, 1983; C.A.M. SENGÖR, 1985; A.A. BELOV et al., 1986; J. BOULIN, 1988), weil diese tektonischen Strukturen entweder über weite Strecken von post-triassischen Schichten bedeckt oder durch spätere tektonische Ereignisse deformiert sind. Das Erosionsfenster von Aghdarband ist ein solcher isolierter Bereich. In ihm sind ungestörte alt-kimmerische Strukturen freigelegt; außerdem befindet es sich nur 40 Kilometer nördlich des erst kürzlich entdeckten permischen Ozeanbodens und Ophiolith-Gürtels Fariman – Torbat-e-Jam.

⓯ Der Verfasser hatte im Jahre 1988 die Gelegenheit, das Gebiet *von Fariman unter* der Führung von J. EFTEKHARNEZHAD & A. BEHROOZI zu besuchen. Er war sehr beeindruckt von der ozeanischen Gesteinsgesellschaft, die dort zu sehen ist: Siltsteine und feinkörnige Sandsteine mit Fließmarken, gradierter Kalkarenit und roter Kieselschiefer neben Serpentinit und Spilit, der letztere mit Pillow-Textur. Eine Probe von roten Kieselschiefern aus dieser ozeanischen Gesteinsgesellschaft lieferte bestimmbare pelagische Conodonten des jüngsten Unterperms (oberstes Kungarian–unteres Chihsian); sie sind typische Vertreter sowohl der pelagischen circum-pazifischen Permfauna als auch der pelagischen Permfauna der Tethys (KOZUR & MOSTLER).

Eingelagert in diese ozeanische Gesteinsgesellschaft sind Gesteinskörper bestehend aus spätigem Kalk-Arenit, die eine Seichtwasserfauna des etwas älteren Unterperms führen (Asselian–Sakmarian, bzw. Sakmarian–Murghabian; F. BOZORGNIA in: EFTEKHARNEZHAD & BEHROOZI). Es ist anzunehmen, daß diese Kalkkörper von einem benachbarten Schelfgebiet in diesen, wahrscheinlich nicht allzu breiten, permischen Ozeantrog eingeglitten sind.

Eine höhere Einheit dieser ophiolitischen Zone, bestehend aus serizitischen Schiefern, Phylliten und Tonschiefern könnte nach EFTEKHARNEZHAD & BEHROOZI spät-permi*schen bis früh-triassischen Alters sein.*

⓰ Es liegt nahe, diesen noch erhaltenen Ozeanboden als Rest des Paläotethys-Ozeanbodens aufzufassen, der von einer weiter nördlich anzunehmenden und heute unter der Jura-Bedeckung verborgenen permischen Subduktion nicht mehr erfaßt worden wäre. Der Mélange-Charakter der Ophiolithe, die im Darreh Anjir-Tal in der Südwest-Ekke des Erosionsfensters von Aghdarband zutage treten, könnte dahingehend gedeutet werden, daß diese Ophiolithe im Perm auf den Südrand der Turan-Platte obduziert worden wären. Dieser Prozeß müßte schon zu Beginn der Trias-Zeit beendet sein, da ja die unter-skythische Qara Gheitan-Formation auf diese Ophiolithe transgrediert.

Eine solche Hypothese würde allerdings besagen, daß hier die Paläotethys schon im Perm geschlossen wurde, und daß weder ein von BAUD angenommenes „back-arc setting" der ladinischen „Sea of Aghdarband" noch die alt-kimmmerische Orogenese eine direkte Folge des Schließens der Paläotethys gewesen wäre.

⓱ Eine Alternative zu dieser Hypothese wäre die Annahme, daß der genannte Ozeanboden das Ergebnis eines permischen Rift- Vorganges war, der zur Ausbildung eines lokalen ±breiten Ozean-Troges führte. Die Beziehungen, die zwischen Aghdarband und dem Alborz-Gebirge zum Teil während der Trias-Zeit, aber auch im Paläozoikum bestanden, sprechen für diese Alternative. Dies wird auch von H. KOZUR (in: KOZUR & MOSTLER) in einem weiteren Rahmen diskutiert.

In Fig. 3 seiner zitierten Arbeit (1984) zeichnete K. WEDDIGE für die permische Transgression eine „basinal facies area" im Gebiet östlich und westlich von Mashhad nördlich einer „Permian carbonate platform", ohne damals noch etwas von der Existenz eines permischen Ozeanbodens in diesem Bereich gewußt zu haben!

Synopsis

Triassic rocks crop out in the northern part of the erosional Window of Aghdarband between two major faults. The "Northern Main Fault" is a vertical sinistral side slip fault (RUTTNER) separating the Triassic rocks from a slightly metamorphosed Upper Devonian – Lower Carboniferous rock sequence of the "Northern Frame". The "Southern Main Fault", however, is a thrust fault; the slightly metamorphosed clastic rocks of the "Southern Frame" rest on unmetamorphosed rocks of the Triassic along this fault.

Basically, the internal structure of the Triassic is that of a large WNW–ESE trending syncline ("Aghdarband Syncline"). At its northern flank, a narrow strip of steeply inclined Triassic rocks ("Slice I") follows the Northern Main Fault. It is separated from the central part of the syncline by another vertical fault. This central part ("Slice II") displays a broad synclinal structure in its western part (west of the Aghdarband settlement), accompanied there by a narrow northern anticline; the main folding axis is inclined there at 20° to 30° towards ESE. However, in the area to the east of the Aghdarband settlement the syncline is considerably narrowed and disturbed. The reason for this is a third tectonic unit of the Triassic ("Slice III") which is a thrust sheet being pushed from the SSW against the syncline. The facies of the Triassic represented in Slice III differs somewhat from that displayed in Slices I and II, representing a more southerly one.

The Paleozoic rock sequence exposed in the Northern Frame of the Triassic consists of

1) a dark grey thinly-bedded limestone interbedded with volcanic sandstone and containing Frasnian–Famennian conodonts (H. P. SCHÖNLAUB; B. HAMDI in EFTEKHARNEZHAD & BEHROOZI),
2) a dark-green coloured and extremely hard rock unit, consisting mainly of volcaniclastics (breccia, microbreccia, sandstone, "crystal mush"), slate and acidic (andesitic to dacitic) dykes (E. KIRCHNER in RUTTNER), with a limestone-layer of Famennian age on its top,
and
3) a recrystallized limestone ("marble"), which yielded a microfauna indicating a Tournaisian age (B. HAMDI in EFTEKHARNEZHAD & BEHROOZI). Pebbles of a conglomerate exposed at the base of this limestone contain an Upper Devonian/Lower Carboniferous microfauna.

EFTEKHARNEZHAD & BEHROOZI compare this Paleozoic rock sequence with the Paleozoic of the central Alborz Mountains (Geirud Formation, Mobarak Limestone). RUTTNER, on the *other hand still considers it to be part of the Hercynian base*ment of Kopet Dagh and equates it with rock-sequences of the same age as described e.g. from the parautochthonous Caucasian Forerange.

The southern Frame is composed of five structural units (thrust sheets); they consist of quarzitic sandstone, violet-red or greenish-grey in colour, sericitic slate also violet or green, and some layers of conglomerate in the sandstone. The lowermost structural unit is a tectonic mixture of these slightly metamorphosed rocks and unmetamorphosed Triassic rocks. Close to the eastern margin of the erosional Window, large bodies consisting of Triassic and recrystallized (?)Carboniferous limestone respectively, are involved in this tectonic mixture (EFTEKHARNEZHAD & BEHROOZI).

RUTTNER considers the slightly metamorphosed slates and sandstones of the Southern Frame to be the original late- to post-Hercynian basement of the Triassic – comparable for instance with the Upper Carboniferous and/or Permian of the Caucasian Forerange – being the overturned, imbricated and overthrusted southern limb of the Aghdarband Syncline.

These rocks of the Southern Frame are bordered to the southwest by the Shahtutak Fault, which separates them from a more than 1000 meters thick sequence of unmetamorphosed shales, sandstones, gritstones, and conglomerates of brownish-red to (partly) greenish colour; this sequence of clastic rocks occupies nearly the entire southern half of the erosional Window of Aghdarband.

Significantly a pink granite occurs among the well-rounded components of the conglomerate layers, apart from various volcanic rocks, chert, quartzite, and quartz. In the southern part of the Window, limestone pebbles contain a microfauna which point to a Carboniferous and – in one case – to a late Permian age of the limestone in the source area of these pebbles (EFTEKHARNEZHAD & BEHROOZI). In the south, these two authors found a normal transgressive contact of these clastic rocks with the Permian ophiolitic rocks of Darreh Anjir.

However, in the northern part of the window, the same rock sequence underlies the Late Scythian Sefid Kuh Limestone; the contact is exposed at the northwestern foot of Sefid Kuh, to the Southeast of the small settlement of Qara Gheitan, which gave the (unofficial) name Qara Gheitan formation to this Early Scythian rock sequence. RUTTNER compares this formation with the upper (Triassic) part of the "Hercynian Molasse", as described by Russian authors from the Caucasian Foreland. EFTEKHARNEZHAD & BEHROOZI include the slightly metamorphosed rocks of the Southern Frame in the Qara Gheitan formation.

The Shahtutak Fault divides the erosional Window of Aghdarband into two heterogenous parts. Along this fault BEHROOZI found elongated bodies of rocks comparable partly with the Upper Devonian and Lower Carboniferous rocks of the Northern Frame. This fault is the only structural feature of the Window affecting also the Jurassic coverbeds of the Window (cf. the structural sketch map, Fig. 1). Like the Northern Main Fault, this fault is very probably also a side slip fault; however, the direction of displacement along this fault is not yet known. The Shahtutak Fault possibly marks the southern edge of the Hercynian Turan Plate. Hence we may infer that the Triassic of Aghdarband was deposited on southern marginal parts of this Plate.

This specific Triassic sequence comprises four formations which jointly form the Aghdarband Group (cf. Table 1).

A characteristic feature of the Sefid Kuh limestone Formation is an alteration of thickly (meter) bedded to massive yellowish limestone and thinly (centimeter to decimeter) bedded limestone, light grey to bluish-grey in colour; the latter is partly nodular and frequently shows vermiculated features. Layers of cross-bedded calcarenite accentuate the shallow water character of the limestone. In the type section measured by A. BAUD and R. BRANDNER at the western rock face of Sefid Kuh this limestone is 200 meters thick. It is considered by these authors to be "the product of a transgression-regression cycle", attributed to eustatic variations of the Tethyan sea level; "a carbonate ramp is formed by several parasequences, each of them shallowing upwards and consisting of grainstones and packstones, being oolitic and/or pelletoidal, mudstones being strongly affected by bioturbation ('vermiculated limestone'), crinoids ('Holocrinus' sp.), packstone-tempestites, and algal boundstones." According to the conodonts determined by D. DONOFRIO, the Sefid Kuh limestone Formation is Late Scythian (Spathian) in age.

A layer of volcaniclastics, about 15 m in thickness, is exposed at the very base of the limestone; the components of the conglomerate and coarse grained sandstone are of andesitic composition (A. BAUD et al.). The transition of the volcaniclastics into the calcarenites of the Sefid Kuh Limestone happens within three meters; the former are, therefore, included into the Sefid Kuh limestone Formation as its most basal part. However, the contact of these volcaniclastics with the underlaying red conglomerate and sandstone of the Qara Gheitan formation is disputed. A. RUTTNER, along with him J. STÖCKLIN and A. BAUD, see a slight angular unconformity between the bedding planes of the two formations; this is denied by EFTEKHARNEZHAD & BEHROOZI as well as by R. BRANDNER. The latter considers the Sefid Kuh limestone Formation (plus the newly established Nazarkardeh Formation) to be " ... the terminal member of a partly extremely thick stratigraphic sequence which is called 'Hercynian Molasse' in the area to the north of the northern Iranian oceanic Suture Zone."

In the Aghdarband area proper, i.e. to the east of Sefid Kuh, the Sefid Kuh Limestone appears as tectonically truncated bodies along faults.

The newly established Early Anisian Nazarkardeh Formation comprises both a cherty thinly-bedded limestone, overlying the Sefid Kuh Limestone in its type section and an alternating ammonite-bearing sequence of beds, consisting of nodular limestone interbedded with tuffaceous marl, shale and/or sandstone. This latter fossiliferous sequence is exposed at the southeastern slope of Sefid Kuh and was also found sporadically within the mapped Aghdarband area, where it was named "Fossil Horizon 1" in 1983 and 1984 and was considered to represent a kind of transition from the Sefid Kuh Limestone to the volcaniclastics of the overlying Sina Formation. However, new paleontological evidence suggests a considerable stratigraphic gap between "Fossil Horizon 1" and the Sina Formation. Furthermore, the wealth of ammonites found in these beds and their biogeographical significance justifies the establishment of a particular formation. The name is derived from Kuh-e-Nazarkardeh, which is a mountain summit situated 1.5 kilometers to the WNW of the Aghdarband village, commanding an over-all view of the area; the Formation is well exposed at the southwestern flank of this mountain range.

The age of the Formation ist Aegean / Bithynian with respect to the basal cherty limestone, according to the conodonts (D. DONOFRIO) and Bithynian with respect to "Fossil Horizon 1", according to the ammonites (L. KRYSTYN & F. TATZREITER). In the latter, two ammonite zones were identified: the upper *Ismidicus*-zone containing the marker fossil *Aghdarbandites* n.g. *ismidicus* (formerly *Anagymnotoceras ismidicum*) and the lower Osmani-zone with its key fossil *Nicomedites osmani*. Remarkably, fossils of the Osmani-zone were found only in the structural Slices I and II so far, and fossils of the *Ismidicus* zone only in structural Slice III.

Treated as a whole, the "*Nicomedites* association" of both Bithynian ammonite zones (L. KRYSTYN in: KRYSTYN & TATZREITER) characterizes faunistically the Early Anisian North Tethyan biogeographical subprovince. According to KRYSTYN, this peculiar fauna is clearly separated from the contemporaneous fauna of the South Tethyan subprovince (i.e. the Tethys province s.str.). It can be traced over a distance of 5000 kilometers from Gebze (SE of Istanbul) along the southern margin of Triassic Laurasia to Qilian Shan (Maduo, northern China); it is found again at the eastern margin of triassic Laurasia in the area to the east of the Sea of Okhotsk (see Figs. 3 and 4 in: KRYSTYN & TATZREITER, this volume). KRYSTYN favours the assumption of a physical barrier over a mere climatic reason to explain the striking faunal differentiation of the two Tethys subprovinces in Early Anisian times.

Volcanic matter ist the main component of the sequence of rocks which, being 400 to 700 meters thick, overlie the Sefid Kuh and Nazarkardeh Formations and form the Sina volcanic Formation, named after the main tunnel of the eastern part of the coal field of Aghdarband. The Formation is composed mainly of tuffaceous sandstone and shale, with intercalations of tuffaceous limestone, marlstone and marl; a few layers of conglomerate are also interbedded. Sole markings on bedding planes and graded bedding impart some sandstone beds with flysch-like features. According to A. BAUD, G. STAMPFLI, D. STEEN, R. CAS and H. SARP the volcaniclasts as well as the mineral assemblage in the sandstone beds point to an intermediate (andesitic and trachyandesitic) to acidic (trachy-dacitic, even rhyolitic) volcanism in the source area. A general trend of upwardly increasing acidity can be observed within the Formation. A. BAUD and G. STAMPFLI consider the volcaniclastic sediments of the Sina Formation to be deposited in a back-arc basin, situated to the north of an assumed subduction zone.

Two lithological units, defined as members of the Sina Formation, can be distinguished: the lower tuffaceous Sandstone Member and the upper tuffaceous Shale Member; the fossiliferous Faqir Marl Bed ("Fossil Horizon 2") is considered to be the base of the tuffaceous Shale Member.

At present, a reliable age has only been established for the upper Shale Member. The ammonite (*Romanites*) fauna of the Faqir Marl Bed indicates a Late Ladinian age (Longobardian 3) for the base of the Member (L. KRYSTYN & F. TATZREITER); radioalarians and spicules of poriferans, found in a siliceous limestone on top of the Member, point to an Early Carnian (Late Cordevolian) age (D. DONOFRIO). Thus, the tuffaceous Shale Member of the Sina Formation covers the stratigraphic range Latest Ladinian to Early Carnian.

However, the time-rock span of the lower tuffaceous Sandstone Member is not known as well. The finding of *Daonella lommeli* in the sandstone below the Faqir Marl Bed suggests that at least the upper part of the Member is still Late Ladinian in age. With regard to the base of the Member (and of the Sina Formation on the whole) we had only negative age-indications until very recently: no Upper Anisian or Lower Ladinian index fossils were known. This suggested the assumption of a stratigraphic gap between the Early Anisian Nazarkardeh Formation and the base of the Sina Formation.

The assumption of such a stratigraphic gap below the volcanic Sina Formation seemed to be confirmed by outcrops of a monomictic limestone conglomerate found at the very base of the Formation in the gorge of the Kal-e-Faqir valley (to the east of Sefid Kuh), as well as 9 kilometers farther to the ESE at the eastern side of the Kal-e-Anabeh valley. The well rounded, but unsorted, pebbles of the conglomerate are up to 10 centimeters in diameter and solely consist of Sefid Kuh Limestone. The overlap of the conglomerate on both, the Sefid Kuh Limestone and the Nazarkardeh Formation, suggests an erosional period having existed before the accumulation of volcaniclastics of the Sina Formation. Such a period of erosion may also explain the sporadic occurrence of the Nazarkardeh Formation in the Aghdarband area. On the other hand, this conglomerate is absent on top of the Nazarkardeh Formation at the southwestern slope of Kuh-e-Nazarkardeh, west of the Aghdarband village. A transitional contact seems to exist there with the Sina Formation.

Lately, the existence of a stratigraphic gap at the base of the Sina Formation has been questioned by finds of conodonts made by D. DONOFRIO in samples of stratigraphic section No. 10 (to the east of Aghdarband village, cf. Fig. 12a) which indicate a Late Anisian to Early Ladinian age of basal parts of the Sandstone Member. There was an erosional phase at the base of the Sandstone Member, but it was obviously locally restricted and an ephemeral one, being the result of a tectonic unrest in connection with the incipient volcanic activity.

The generally green coloured tuffaceous Sandstone Member frequently contains plant remains, mostly stems of *Equisetum* sp., along the bedding planes of the sandstone. Cross-sections through the Member are described in detail by A. BAUD (Sina cross-section) and R. BRANDNER (cf. Figs. 12a and b). The top of the Sandstone Member is a conspicuous and mappable layer consisting of dark green coloured volcanic litharenite of varying thickness (5–10 meters).

Of special interest is a layer of polymictic conglomerate and coarse-grained sandstone, which is about 15 meters thick and interbedded in the Sandstone Member of structural Slice III. Being a mappable keybed at the western slope of the Kal-e-Anabeh valley in the eastern part of the Aghdarband area proper, this layer is named Anabeh Conglomerate. Among well rounded walnut- to fist-sized components (metamorphics, chert, granophyre, volcanic rocks, quartz, and white quartzite), A. BAUD found limestone pebbles of Middle Carboniferous, late to latest Permian, and Early Triassic age. "The roundness of the pebbles and their composition suggest derivation from beaches of gravelbars adjacent to an uplifted crystalline basement". Because the Anabeh Conglomerate is confined to thrust-sheet Slice III, a southerly position of this source area with respect to the Ladinian sedimentary basin may be inferred. RUTTNER (1983, 1984) compared this conglomerate with the Baqoroq Formation of Nakhlak.

The main colour of the tuffaceous Shale Member in the field is dark green to greenish-grey. The shales crumble to thin pencil-like fragments at the surface ("pencil shales"). Interbedded are layers of thinly-bedded fine-grained tuffaceous sandstone and fossiliferous calcareous beds; the former show distinct features of a turbidite. The base of the Member is the Faqir Marl Bed, the top of the Member consists again of a hard, dark green coloured volcanic litharenite, similar to that of the Sandstone Member. The estimated thickness of the Shale Member is 300–500 meters.

The basal Faqir Marl Bed ("Fossil Horizon 2") is remarkable in three ways:

- Its pink an light-green colour makes it conspicuous in the landscape.
- As such it is an important marker bed over nearly the entire area.
- It contains a wealth of mega- and micro-fossils: cephalopods, brachiopods, pelecypods and crinoids, as well as foraminifers and ostracods.

Its name is derived from Kal-e-Faqir, a valley situated at the northwestern edge of the mapped area, where the Bed is well exposed. Lithologically, the Bed consists of layers of shale, marl, tuffaceous marly limestone, and tuffaceous calcareous sandstone. A. BAUD characterizes it generally as a "marly skeletal tuffaceous sandstone".

The ammonoid fauna of the Bed is strikingly uniform over the entire mapped area. It is characterized by the dominance of the genus *Romanites*, and "the association may therefore be called *Romanites*-fauna" (L. KRYSTYN & F. TATZREITER). According to these two authors, this fauna represents the *Frankites regoledosus* zone of the Upper Ladinian (Longobardian 3). Unlike the ammonites of the Bithynian Nazarkardeh Formation ("Fossil Horizon 1"), the Late Ladinian *Romanites*-fauna of the Faqir Marl Bed (5 genera) is a tropical one, occurring over the entire Tethys realm. The same is the case with the pelagic crinoids, the holothuroids and ostracods (E. KRISTAN-TOLLMANN), and the foraminifers (R. OBERHAUSER). Besides the ammonites, the Faqir Marl Bed is characterized by nautiloids, stems of *Traumatocrinus caudex* (KRISTAN-TOLLMANN) and by abundant specimens of the brachiopod *Tethyspira* n. gen. *persis* n. sp. (M. SIBLÍK).

The interbeds of thinly-bedded fine-grained tuffaceous sandstone in the Shale Member display well preserved flow-casts, ripplemarks and indeterminable plant remains along the bedding planes. These turbidites, in combination with "thin-bedded calcareous shale and marl with pelagic bivalves, sponge spicules and isolated crinoid stems suggest a distal, deep ramp environment" (A. BAUD) for the Shale Member.

Finds of *Daonella lommeli* in the shales close to the top-litharenite of the Member suggest that most of the Shale Member is still Latest Ladinian in age. The very top of the Member, however, is Early Carnian. This is proved by a sample taken from a layer of silicaceous limestone which outcrops, about 80 cm thick, between tuffaceous sandstone immediately below the Aghdarband Coal Bed at a ridge ESE of the Aghdarband settlement. A rich assemblage of radiolarians and sponge-spicules, found by D. DONOFRIO in that sample, point to a Late Cordevolian age of this limestone.

The Aghdarband Coal Bed represents the lowermost part of the Miankuhi Formation, which is, for the rest, a monotonous sequence of brown coloured shales with some interbedded siltstones and/or fine-grained sandstones. This Formation forms the core of the Aghdarband Syncline and is named after the Miankuhi region situated to the west of the Aghdarband village.

The coal seam is generally about 1 meter thick and is underlain by a root clay, consisting either of coaly shale or of bleached and decomposed tuffaceous sandstone; it is, in fact, an autochthonous coal seam. Plant bearing dark-grey shales compose the hanging wall of the seam, grading upwards into brown weathering thick-bedded non-tuffaceous sandstone, the latter being generally up to 5 meters thick. This "hanging sandstone" also contains plant remains, and, in its turn, grades upwards into the shales through alternate layers of sandstone and shale.

The plant remains of the hanging wall of the coal seam point to a Norian age, according to the cautious statement of M. BOERSMA & J.H.A. VAN KONIJENBURG-VAN CITTERT: "The dominance of *Podozamites paucinervis* is striking. A comparable flora, also dominated by *Podozamites* is the Norian flora of the Amba river, southern Prmorye, U.S.S.R." .... "So a Norian age seems more probable than a Karnian or Rhaetian one".

Consequently, the existence of a considerable stratigraphic gap between the top of the Sina Formation and the base of the Miankuhi Formation has to be assumed, comprising the upper part of the Carnian and possibly also the lower part of the Norian. The volcaniclastic sedimentation ceased in the Early Carnian, and a new transgression commenced with growing fens on a weathered surface, probably not before the Norian.

A conglomerate and a coarse cross-bedded sandstone is exposed below the Coal Bed in the western part of the mapped area. Reworked volcanic rocks predominate among the well rounded but unsorted pebbles which range from fist- to head-size. This, too, gives indication of a quick shallowing, and, finally, vanishing of the Ladinian sea in Early Carnian times.

Apart from the plant remains, the Miankuhi Formation did not yield any other megafossils, nor any pollen or spores. In samples of the shales R. OBERHAUSER found a poor association of agglutinated tests of foraminifera. This benthonic fauna does not give any chronostratigraphic indication; however, it points to an extremely adverse – though marine – living environment.

The shales of the Miankuhi Formation are the youngest sediments affected by the Early Cimmerian orogeny.

The Cimmerian structures are covered by the Kashafrud Formation. Generally, the lowermost part of this Formation is a conglomerate, which lies unconformably on the Cimmerian folded and faulted rocks. Marine fossils of Bajocian age appear not earlier than 170 to 200 meters above the base of the Formation.

However, at Ghal'eh Qabri, about 11 kilometers to the ESE of the Aghdarband village, the Cimmerian structures are unconformably overlain by a white sandstone being the base of a sequence of black shales, named here the Ghal'eh Qabri Shales. Apart from coal streaks, this white sandstone contains plant remains. Several specimens of these, collected close to the ruins of the fortress Gal'eh Qabri (site 75/3) were studied by M. BOERSMA & J. VAN KONIJNENBURG-VAN CITTERT and classified to be very probably Rhaetian in age: "Notably site 75/3 allows a more precise dating. Of the seven species recorded two occur in the Rhaetian only, viz., the two species of *Pterophyllum*. One species, viz., *Stachyotaxus elegans*, has been recorded from Rhaetian sediments in, e. g., East Greenland, Sweden, Afghanistan and U. S. S. R. (Issyk-kul), with only one Karnian/Early Norian occurrence in the Yamachuti Formation. The remaining four species are of a type commonly found in Upper Triassic and Jurassic. Thus, a Rhaetian age for site 75/3 seems more probable than a Karnian or Norian one" and: "An assignment to the Jurassic can be excluded since at least three species have been encountered that disappear at the Rhaetian–Liassic boundary, viz., *Stachyotaxus elegans, Pterophyllum* cf. *subaequale* and *Pterophyllum* cf. *ptilum*".

It is not yet decided whether the Ghal'eh Qabri Shales, and particularly their plant bearing basal part, is to be considered as a locally developed individual formation or as a basal part of the Kashafrud Formation. But, nevertheless, the Early Cimmerian orogeny becomes confined by this florule and by that of the Aghdarband Coal Bed to the time-span ?Late Norian–Early Rhaetian.

A mild young-Alpidic (Tertiary) orogeny resulted in a dome-like uplift of the Aghdarband area, which gave rise to the origin of the erosional window. After the removal of the cover-beds – probably in Late Tertiary times – the landscape was eroded to a peneplain which is still preserved as a vast plateau to the south of the Aghdarband area proper. Loess covers wide areas of this peneplain-highland and parts of its slopes towards the north, and even low-lying areas to the east and west of the Aghdarband village. Loess sedimentation took place probably during long phases of the Pleistocene.

After a long period of tectonic rest (?latest Tertiary – early Quaternary), which resulted in the development of the peneplain mentioned above, the uplift of the Aghdarband area started again, giving rise to an intensified erosional activity through the Kashaf Rud river and its tributaries. This uplift is still going on; the Kashaf Rud cuts deeply in alluvial terraces, which are well developed being of the order of several meters above the riverbed.

1. Introduction

The impulse for this paper came from a small coal mine which is situated in the remote area of Aghdarband, 100 kilometers to the east-southeast of Mashhad, the capital of the province Khorasan. The name Aghdarband (spelled also AqDarband or Akdarband) is derived from a pass of this name, situated 35 kilometers WNW of the coal mine in the Mozduran Mountains of the Kopet Dagh Range, on the road from Mashhad to Sarakhs.

Unlike most Iranian coals, the one of Aghdarband is a coking coal. The coke, produced in primitive coke ovens, was – and is – mostly used locally in sugar refineries. In the seventies, an enlargement of coke production became desirable during the course of the industrialisation of Iran. The owners of the mine, the esteemed Iranian company "Société Minak", considered therefore a replacement of the primitive coke ovens by a modern coking plant.

One of the preconditions for such an investment was the knowledge of the remaining coal reserves in the mining area. This again required a detailed geological map of the area, in order to unravel its complicated structure.

Equipped with excellent topographic maps at the scale of 1 : 5.000, the present writer undertook this task during the years 1975 and 1976. Economically, these efforts did not bring the desired results: a calculation of the coal reserves, based on the resulting map, did not meet the requirements for an expansion and modernization of the coke oven plant. Scientifically, they generated a wealth of new information with respect to the stratigraphy and structure of this interesting area.

Fossils and rock samples, collected during the mapping campaign, were studied by specialists in Vienna, Innsbruck, Prague and Utrecht. Detailed stratigraphic sections, measured independently by J. STÖCKLIN (1969, 1972), A. BAUD (1972) and R. BRANDNER (1977), complete the geological map. Recent findings made by J. EFTEKHARNEZHAD and A. BEHROOZI brought about important stratigraphical corrections. New paleontological finds, made by D. DONOFRIO as recently as this paper was already printing, originated stratigraphical amendments which still could be taken into consideration. A detailed cross section through the area just to the west of Aghdarband village was provided by R. BRANDNER in the same time; it is annexed to this paper in the form of an addendum (Fig. 54).

This paper is intended to present results of the present writers own fieldwork and structural analysis, as well as those of all other contributors, as far as they are relevant to the geological picture of the area.

The geological map of the mining area was printed in 1984 at the scale of 1 : 12.500 (cf. Plate 1). Further studies, discussions and considerations made necessary a number of corrections to the legend of this map. The former Triassic Aghdarband Formation became the Aghdarband Group, consisting of four well defined formations. Likewise, a few petrological and stratigraphical details had to be amended. The corrected legend is to be found on Plate 3 (Geological Contour Map and Diagrams, 1988).

The progress in knowledge of the geology of the area, in the course of recent years, implies also some modifications in comparison with earlier publications (RUTTNER, 1980, 1983, 1984).

2. The Erosional Window of Aghdarband

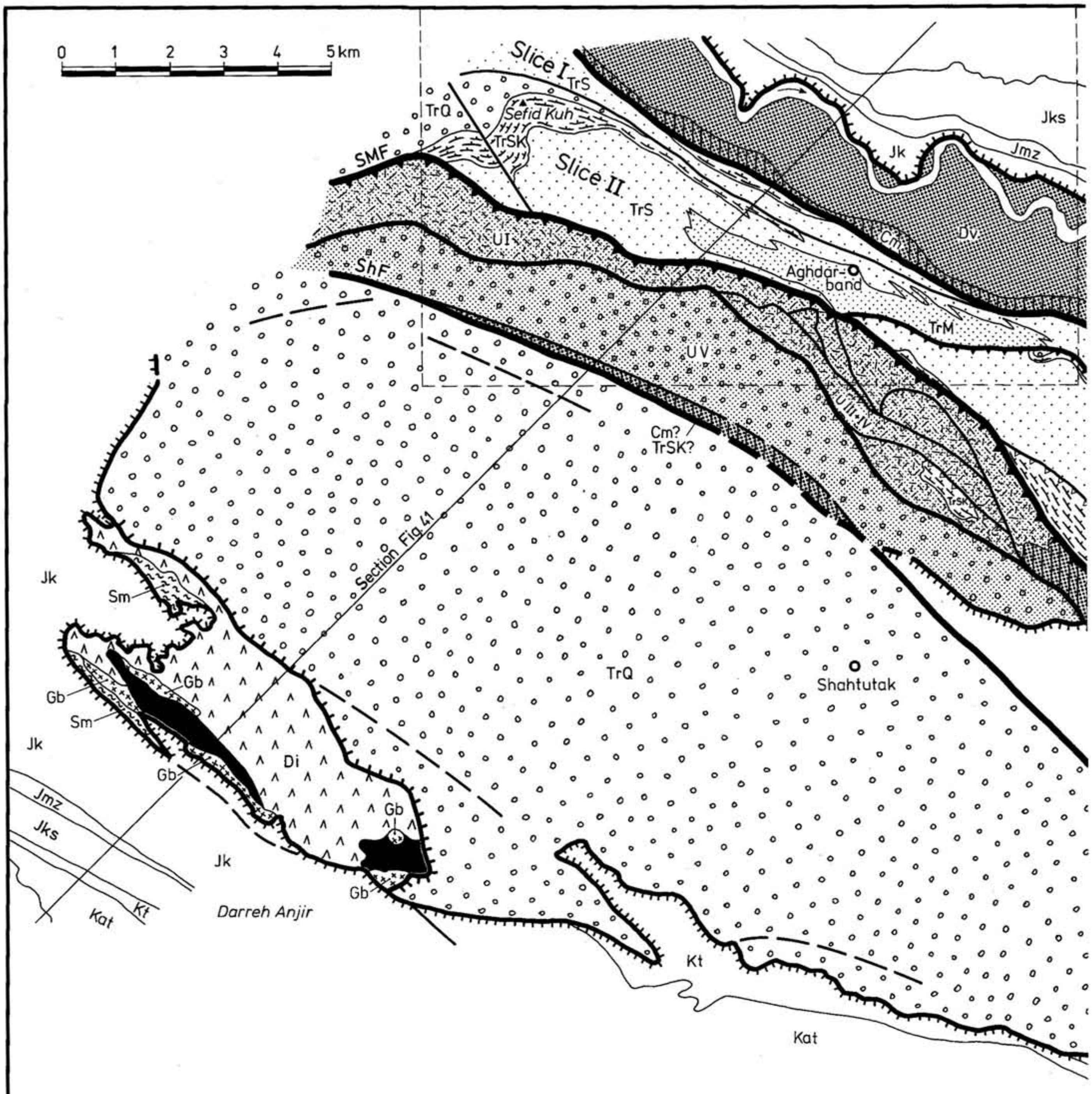
(Fig. 1)

2.1. General Setting

The Kopet Dagh Range, which stretches over nearly 700 kilometers in WNW–ESE direction east of the Caspian Sea from the U. S. S. R. over Iran into Afghanistan is composed of a gently folded rock sequence which – 5000 to 7000 meters in thickness – comprises the Middle and Upper Jurassic, Cretaceous, Paleocene and Eocene. The base of this rock sequence is only exposed in the eastern part of this mountain range in Iranian territory. There, a gentle doming of the beds is eroded down to the pre-Jurassic basement by the river Kashaf Rud, its tributaries, and by another drainage pattern to the south. So, the basement of Kopet Dagh is exposed to the surface over an area extending about 20 kilometers in length and 15 kilometers in width.

In 1956 the Swiss geologist K.T. GOLDSCHMID (1956) recognized for the first time the striking angular unconformity on top of this basement. He suggested the name Kashafrud Formation for the lowermost Jurassic unit of the covering rock sequence. This Formation encircles nearly the whole window (cf. Fig. 1 in EFTEKHARNEZHAD & BEHROOZI, this vol.). Generally, the basal member of the Formation is a conglomerate, which is up to 90 meters thick in the area close to the Aghdarband coal mine (MADANI, 1977; DAVOUDZADEH & SCHMIDT, 1981). The oldest marine fossis found so far in the Formation are ammonites of Bajocian age; they are preserved in calcareous nodules, which are interbedded in black shale, at least 200 meters above the Formation's base. The age of the very base of the Formation is discussed in chapter 3.2.4.

The erosional Window of Aghdarband is divided into two parts by the WNW–ENE trending Shahtutak Fault (cf. Structural Sketch Map, Fig. 1). The main scope of the present paper concerns the northern part of the Window. There, rocks of the Triassic Aghdarband



Ophiolithic Assemblage

- Ultrabasic rocks
- Gb — Gabbro
- Sm — Phyllitic rocks and intercalated recrystallized limestone
- Di — Diabasic rocks subordinate tuffs, radiolarite, radiolarian chert, calcareous and radiolarian siltstone

Jurassic and Cretaceous Cover

- Kab — Abderaz Formation
- Kat — Atamir Formation
- Kt — Tirgan Formation
- Jks — Shurijeh Formation
- Jmz — Mozduran Formation
- Jk — Kashafrud Formation

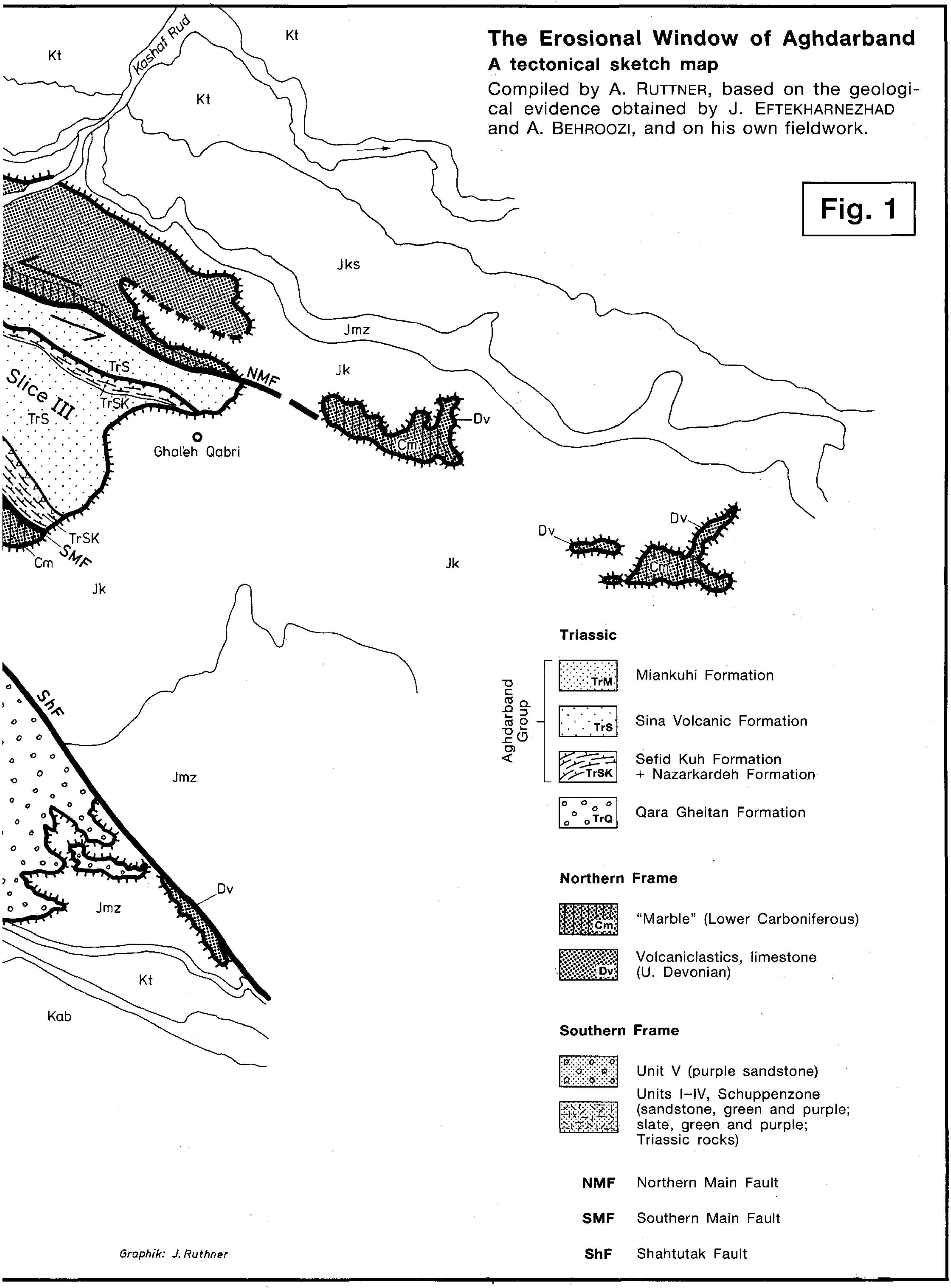
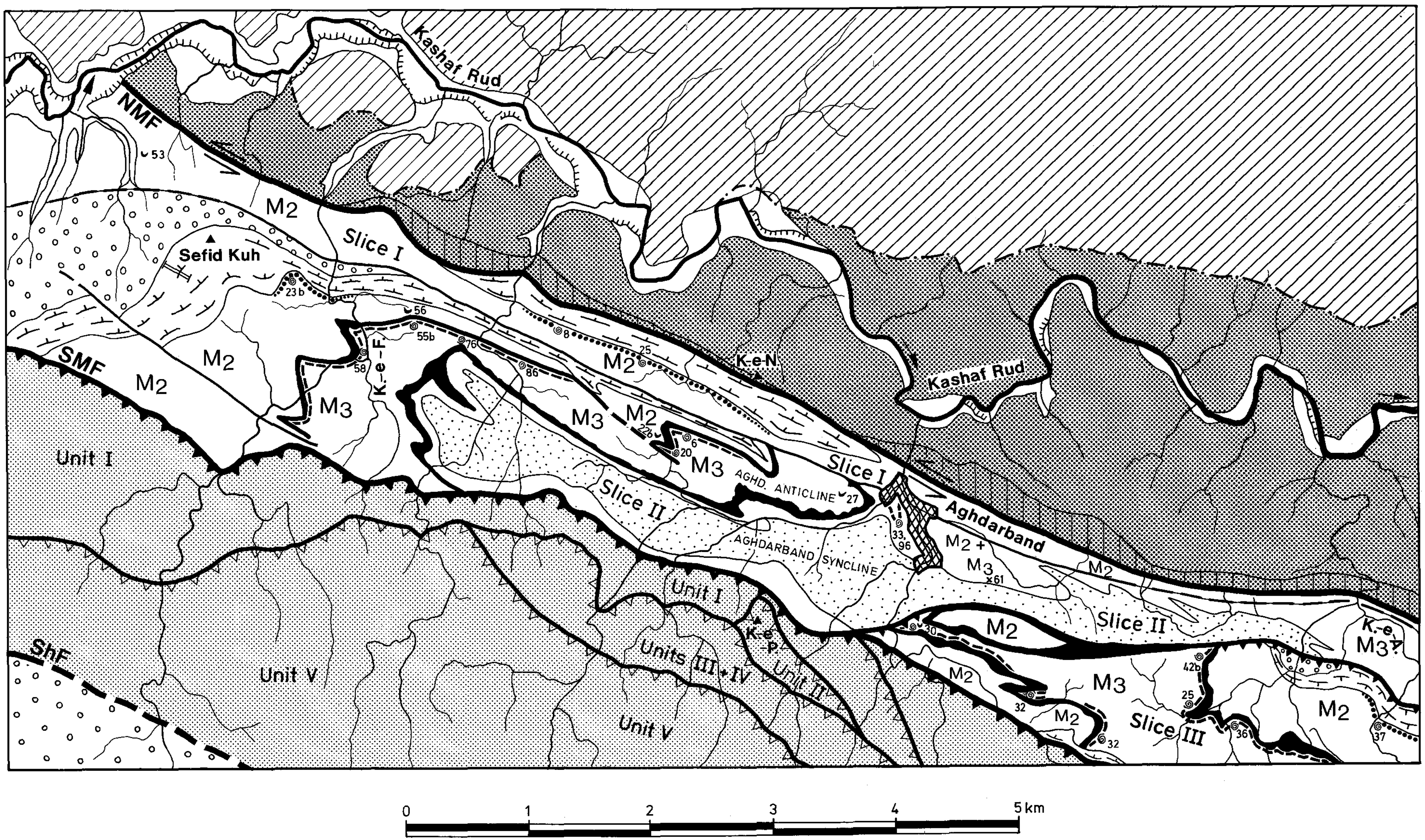
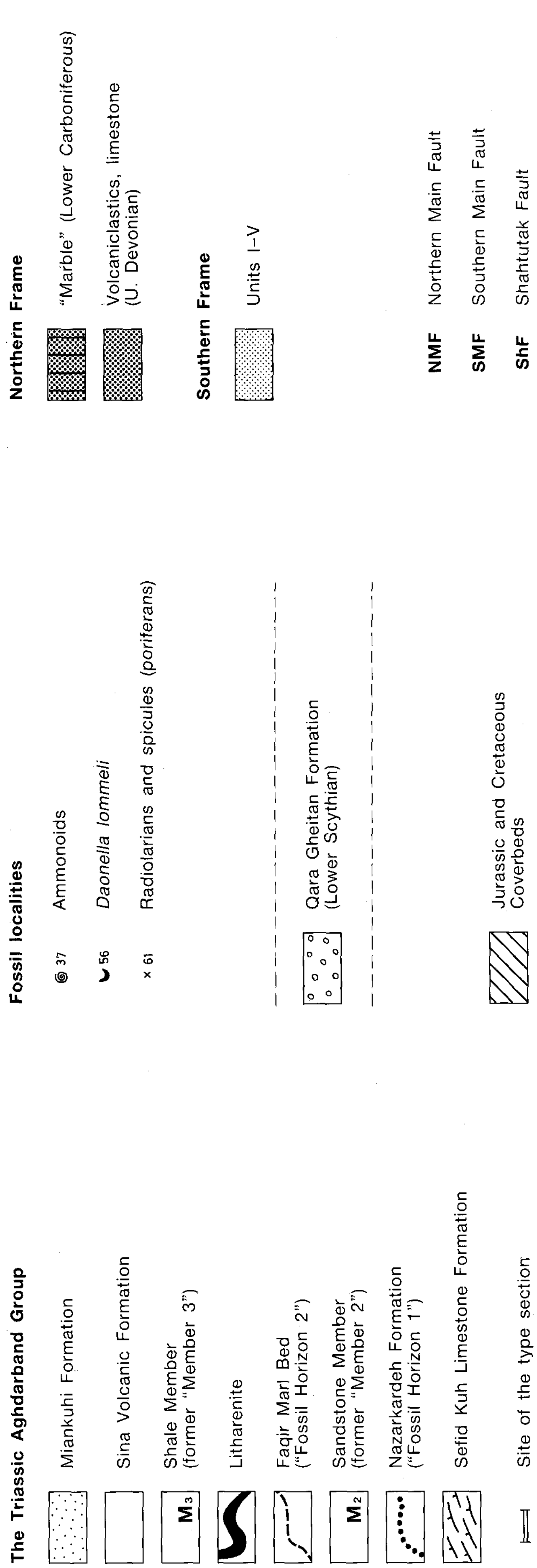

The Erosional Window of Aghdarband
A tectonical sketch map
Compiled by A. RUTTNER, based on the geological evidence obtained by J. EFTEKHARNEZHAD and A. BEHROOZI, and on his own fieldwork.
Fig. 1
Kt
Kashaf Rud
Jks
Jmz
Jk
NMF
Dv
Cm
TrS
TrSK
Slice III
Ghaleh Qabri
SMF
ShF
Kab
Triassic
Aghdarband Group
TrM
Miankuhi Formation
TrS
Sina Volcanic Formation
TrSK
Sefid Kuh Formation + Nazarkardeh Formation
TrQ
Qara Gheitan Formation
Northern Frame
Cm
"Marble" (Lower Carboniferous)
Dv
Volcaniclastics, limestone (U. Devonian)
Southern Frame
Unit V (purple sandstone)
Units I–IV, Schuppenzone (sandstone, green and purple; slate, green and purple; Triassic rocks)
NMF Northern Main Fault
SMF Southern Main Fault
ShF Shahtutak Fault
Graphik: J. Ruthner

Fig. 2.
The northern part of the Window of Aghdarband.
A geological sketch map.
K-e-N = Kuh-e-Nazarkardeh; K-e-P = Kuh-e-Palang.





Group outcrop in a WNW–ESE trending narrow strip (20 kilometers long and 2 to 4 kilometers wide) between slightly metamorphosed Upper Devonian to Lower Carboniferous rocks to the north ("Northern Frame") and a schuppen-zone composed of red and green coloured slightly metamorphosed clastic rocks of disputed age to the south ("Southern Frame"). To the north, the Triassic is bounded by a sinistral side-slip-fault, to the south, however, by a thrust-fault. Farther to the south, the schuppenzone is cut off by the Shahtutak Fault, which is, very probably, again a side-slip-fault.

The geological map of the coal mining area (Plate 1) shows a central section of this northern part of the window.

In the southern part of the window, a large area is occupied by an extremely thick sequence of red coloured conglomerate, sandstone, siltstone and silty shale. Limestone pebbles, containing Carboniferous to Late Permian microfossils indicate an Early Triassic (Early Scythian) age of these beds (cf. EFTEKHARNEZHAD & BEHROOZI, this vol.); they correspond to the "Hercynian Molasse" of Russian geologists and are comprised here provisionally as Qara Gheitan formation.

At the southwestern edge of the erosional window, a basal conglomerate of this formation rests transgressively on Permian ophiolitic rocks (cf. EFTEKHARNEZHAD & BEHROOZI, this vol.). In the northern part of the window, however, the Qara Gheitan formation underlies the basal limestone formation of the Aghdarband Group, which is Late Scythian in age (cf. chapter 3.1.).

2.2. The Northern Part of the Window

(Fig. 2)

The rather complicated structural pattern of the northern part of the Window necessitates a short structural outline before going into any stratigraphic details.

In the closely studied central section of this part of the Window, i. e. in the Aghdarband area proper, the general shape formed by the Triassic beds is that of a WNW–ESE trending synclinorium. To the west of the village of Aghdarband, in the area known as Miankuhi (= "between the mountains"), a broad syncline is clearly seen on the map (Plate 1) named Aghdarband Syncline. In the area to the east of the village, however, the syncline is strongly compressed, folded and overthrust by its southern limb (see cross-sections Plates 2 and 4).

In order to facilitate the presentation of details on facies, stratigraphy and sedimentary petrology, A. BAUD recommends the differentiation of three structural units (slices), which, in a broader sense, all form part of the Aghdarband Syncline:

Slice I : Pertains to the vertically faulted and folded northern limb of the Syncline along the Northern Main Fault.

Slice II : Pertains to the main central part of the Syncline and to a narrow northern anticline in the western part of the area.

Slice III: Includes a thrust-sheet composed of the southern parts of the Syncline, which are thrust over Slice II.

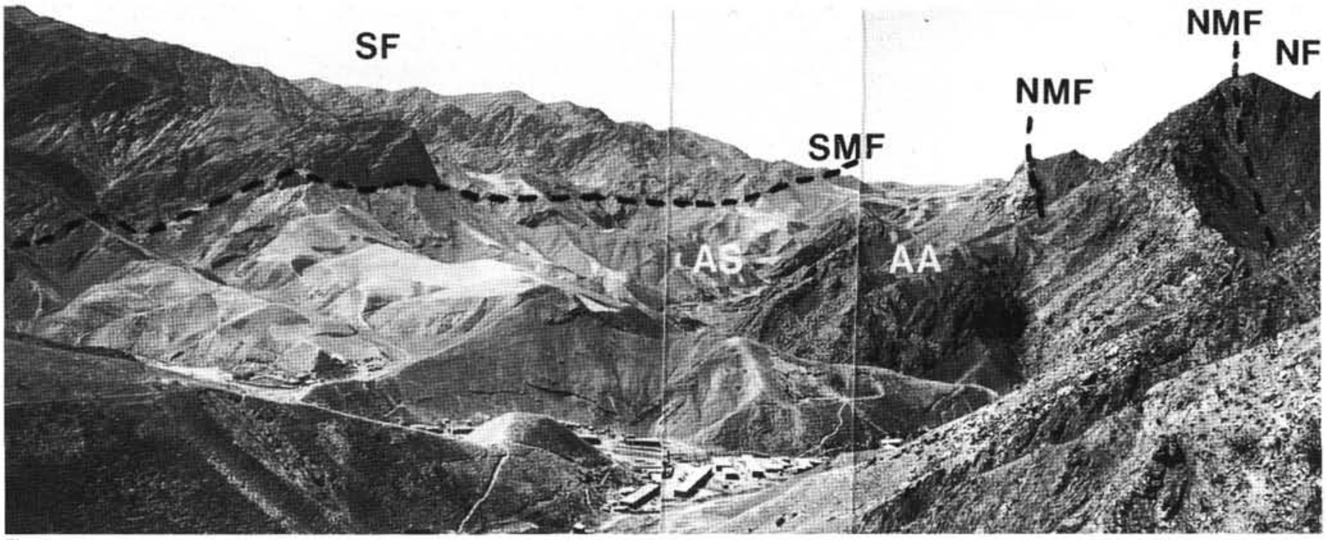


Fig. 3.
General view of the Aghdarband area (from east).
SF = Southern Frame; NF = Northern Frame; SMF = Southern Main Fault; NMF = Northern Main Fault; AS = Aghdarband Syncline; AA = Aghdarband Anticline.

These three structural slices are shown on the geological sketch map, Fig. 2 and in the cross-sections, Plate 4.

The vertical fault separating Slice I from Slice II is clearly evident in the central part of the area only, i. e. in the region to the west and to the east of Aghdarband village. In the western part of the mapped area (Miankuhi), the fault becomes somewhat obscure, and in the easternmost part of the mapped area (Sina-region) the separation of the two slices is not quite clear either (cf. chapter 6.2., structural Slice I).

In contrast, the thrust-fault between Slice II and Slice III is clearly evident in its course up to the eastern edge of the mapped area. Slice III possibly represents an area, which originally may have been considerably further south, before the event leading to the thrust over Slice II occurred. This possibility shoud be taken into consideration when discussing the differences in facies which exist between Slice III and Slices I + II.

A general view of the Aghdarband area shows the panorama, Fig. 3.

3. The Triassic of Aghdarband

(Table 1 and columnar sections Fig. 4)

3.1. The Early Scythian Qara Gheitan Formation

(Nos. 23 and 24 on the geological map Pl. 1)

Representative exposures of the sedimentary base of the Triassic Aghdarband Group could not be found within the Aghdarband area proper shown on the map (Plate 1). Outside this area and of easy access from the Kashaf Rud valley, these rocks are well exposed farther to the west in the hills west of Sefid Kuh, south of the small settlement of Qara Gheitan. There, a sequence of shales, sandy shales, sandstones,

Table 1.
The Triassic of Aghdarband.

Ghal'eh Qabri shale Beds = Base of Kashaf Rud Formation?				Rhaetian
Aghdarband Group	Miankuhi shale Formation		Aghdarband Coal Bed	Norian
				Carnian
	Sina volcanic Formation	Tuffaceous Shale Member	Faqir Marl Bed = "Fossil Horizon 2"	Ladinian
		Tuffaceous Sandstone Member		Anisian
	Nazarkardeh Formation		= "Fossil Horizon 1"	
	Sefid Kuh limestone Formation			Scythian
Qara Gheitan Formation ???				Permian

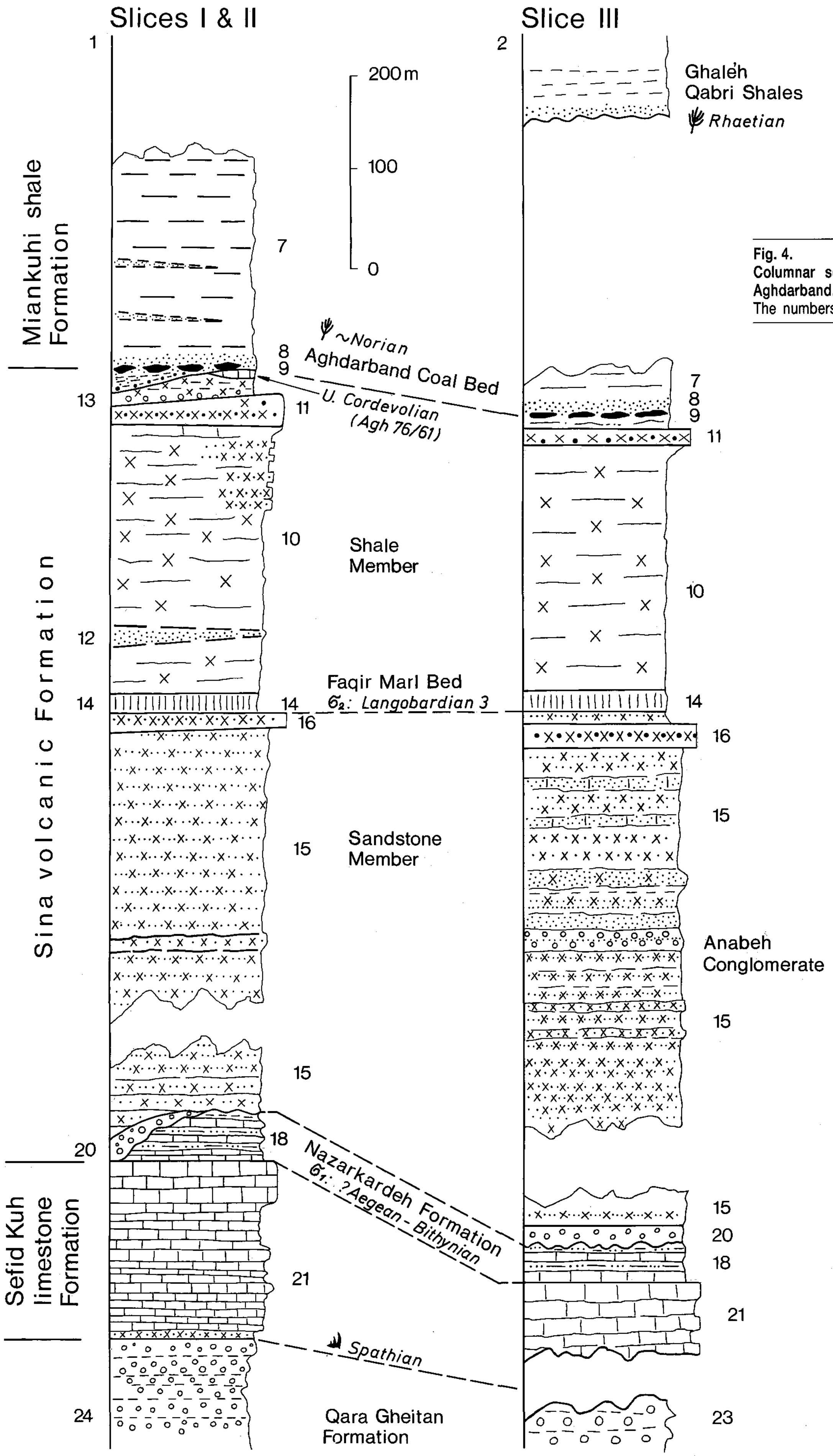


Fig. 4.
Columnar sections of the Triassic of Aghdarband.
The numbers refer to Plate 3.

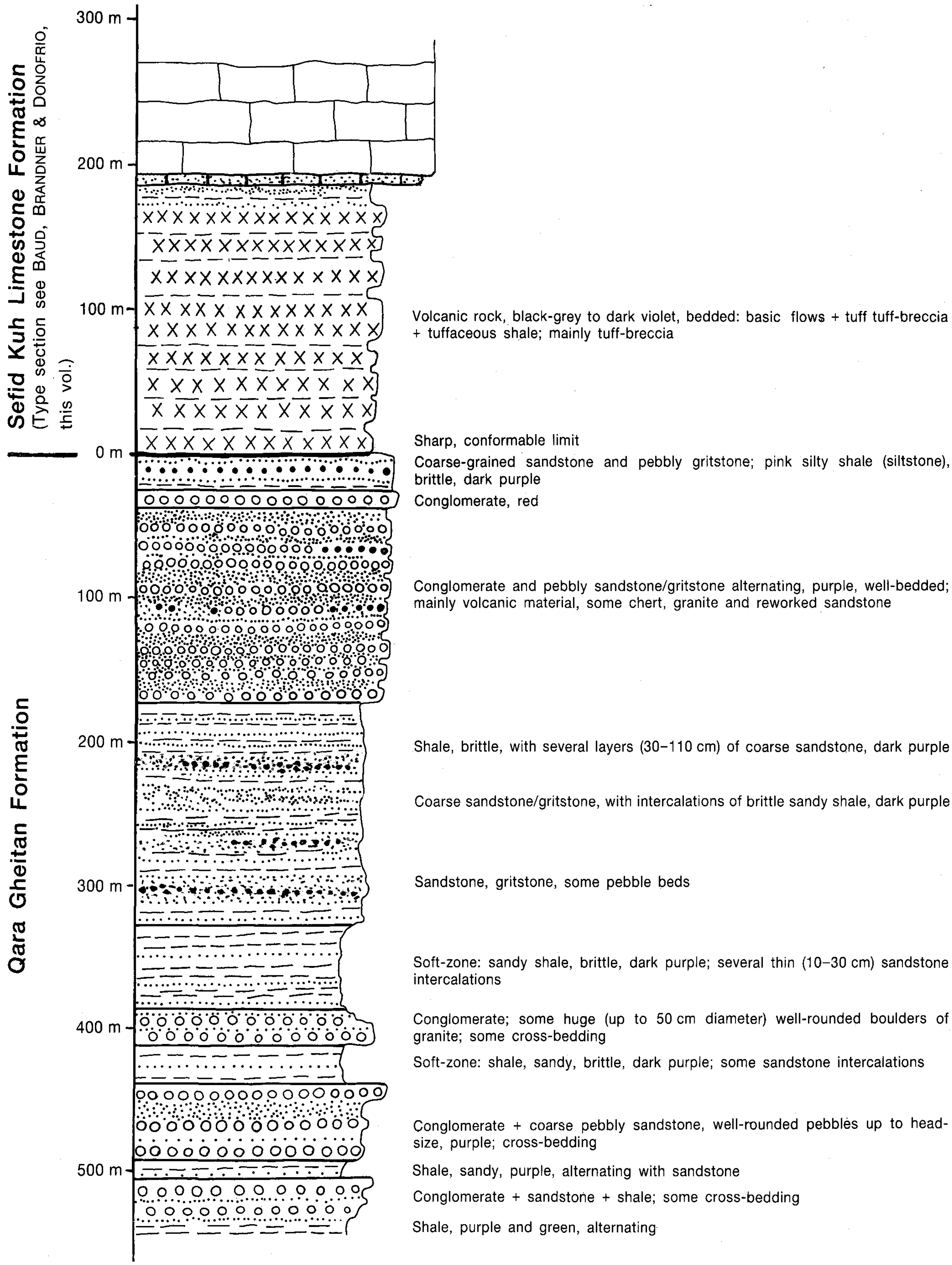


Fig. 5.
Qara Gheitan formation, upper part.
Section measured by J. STÖCKLIN (5. 5. 1972) at the western foot of Sefid Kuh, to the north of Qara Geitan.

gritstones, and conglomerates outcrop below a blanket of loess and alluvial debris. This sequence of rocks is now informally named Qara Gheitan formation.

A brownish-red colour is a characteristic of all these rocks; the layers of conglomerate and coarse sandstone are generally somewhat lighter in colour than the interbedded fine grained sandstones and shales. Westward these beds are bounded by faults; in the east – at the foot of Sefid Kuh – they are overlain by the (Late Scythian) Sefid Kuh Limestone Formation of the Aghdarband Group.

The well rounded components of the conglomeratic layers range in size up to 20 centimeters, and more, in diameter. Significantly, a pink granite occurs among the rocks composing this conglomerate.

A section measured by J. STÖCKLIN at Qara Gheitan (5. 5. 1972) is representative of this sequence of beds and is shown in Fig. 5. As a summary for that section, STÖCKLIN wrote in his field book:

"The sandstones are soft, friable, molasse-like, from pink (coarse sandstones) to dark purple (silty shales). The formation is well and thick bedded, but stratification is poorly developed in the sandstones. Conglomerates appear as regular layers or lenticular patches, in general clearly layered. Crossbedding is only slightly developed, and in various directions. Pebbles are well rounded. Also typical are coarse sandstones and gritstones with large scattered pebbles. Sandstones are not micacious; quartz and feldspar predominate. Granite pebbles (pink granite with biotite) are abundant, though subordinate to volcanic material (dark green and violet porphyrites, tuffs, etc.). Apart from the volcanics and granite, the main components are red chert, quartzite, ?quartzporphyry, red 'granitic' sandstone and quartz. Red siltstones and silty shales change to light green along cracks and fissures. Some sandstones show 'spherical' weathering. No ripplemarks, no clay in cracks and no organic remains were observed."

The thickness of the Qara Gheitan formation in this section is 600 meters. STÖCKLIN notes volcanic rocks overlying these beds of the Qara Gheitan formation, having a thickness of 180 meters. Somewhat south of this section, the present author saw also about 15 meters of a dark green tuffaceous rock (combined with a black conglomerate) in the same geological position below the Triassic limestone of Sefid Kuh. These volcaniclastics are considered to form the most basal part of the Sefid Kuh limestone Formation (cf. chapter 3.2.1.).

A vast area is composed of the same alternating red shales, sandstones and conglomerates in the southern part of the highlands to the south of the Shahtutak Fault, and as far as to the southern edge of the erosional Aghdarband Window (cf. J. EFTEKHARNEZHAD & A. BEHROOZI, this vol., Fig. 1). Limestone pebbles found first by J. STÖCKLIN (1972) in conglomerate layers yielded microfossils which point to a Carboniferous and, in one case, to a late Permian age of the limestone as the source of these pebbles (KASHANI, in EFTEKHARNEZHAD & BEHROOZI, this. vol.; see also chapter 5.2., Southern Frame). These pebbles and the formation's position below the Late Scythian Sefid Kuh Limestone Formation assigns an Early Scythian age to the Qara Gheitan formation.

In Russian literature these rocks are referred to as "post-Hercynian Molasse", but unfortunately the original sedimentary contact of the Qara Gheitan formation on its basement is not exposed in the Aghdarband area. The present author originally considered the red-brownish coloured shales and sandstones, which south of the mapped Aghdarband area outcrop below the loess cover of the plateau, to be overlying the quartzitic purple sandstone of the Southern Frame proper (see RUTTNER, 1984, Fig. 3). However, a close scrutiny of air photos and Landsat images as well as now the fieldwork of A. BEHROOZI has shown that the contact to this sandstone is a major east-southeast to west-northwest trending fault (Shahtutak Fault, see structural sketch map, Fig. 1).

According to the recent field work of the GSI team, there is a normal transgressive contact of the Qara Gheitan formation to ophiolitic rocks (gabbro, ultramafic rocks, diabase, spilite) in the southwestern corner of the window (Darreh Anjir). A basal conglomerate of the Qara Gheitan formation contains

" ... subrounded pebbles of basic-ultrabasic rocks, radiolarian chert (mainly derived from the underlying Ophiolitic Melange) ... " (EFTEKHARNEZHAD & BEHROOZI, this vol.; see also chapter 6.).

The total thickness of the Qara Gheitan formation is probably more than 1000 meters there.

Within the Aghdarband area proper, however, beds of the Qara Gheitan formation only occur in small outcrops along faults. One of these is located south of tunnel "Sina" of the coal mine, which is situated in the extreme east of the mapped area (Plate 1). At this location, red sandstones alternating with red-brownish to purple coloured shales, with a conglomerate bed at the base of the outcrop, dip southward below the Sefid Kuh limestone Formation. The conglomerate contains well rounded pebbles of greenish coloured quartzporphyry (rhyolite) and reddish coloured granite. Towards the north, both the limestone and the beds of the Qara Gheitan formation are cut off by that thrustfault which separates structural Slice III from Slices II+I in the area east of the Aghdarband settlement (see the chapter "Structure").

The stratigraphic sections 7 and 6, measured by A. BAUD show details of the situation there (A. BAUD et al., Fig. 2 and 3, this vol.).

Although situated at a major fault, rocks of the Qara Gheiten formation, exposed south of tunnel "Sina", are still in contact with their original sedimentary cover. However, on the steep slopes north, northeast and west of the Aghdarband settlement, slices of these rocks are completely cut off from their former sedimentary formation, occurring right at the Northern Main Fault which separates the Triassic of Aghdarband from its Northern Frame. Brownish-red sandstones and red shales, partly discoloured to a greenish hue, are intensively sheared there; they are tectonically mixed with rocks of the Sina Formation as well as with rocks of the Northern Frame. Slices of conglomerate contain pebbles of a greenish coloured quartzporphyry. A hard dark green coloured rock occurs northeast of the Aghdarband settlement within this shear zone. It is – very probably – the same volcanic rock as that one which is exposed on top of the Qara Gheitan formation at the western foot of Sefid Kuh at Qara Gheitan.

Obviously, these slices of rocks of the Qara Gheitan formation are basal parts of the folded and faulted Triassic Syncline of Aghdarband, brought up to the surface by the Northern Main Fault. South of this Triassic syncline, such traces of its base are also recognizable. There, the lowermost wedge of the imbricate structure in the Southern Frame includes bodies of red conglomerate (containing pebbles of red granite and quartzporphyry), sandstone and shale (No. 34 on the geological map, Plate 1), with strong resemblance to the rocks of the Qara Gheitan formation described above. The present writer considers this lowermost sheet of the Southern Frame to be the base of the Triassic synclinorium of Aghdarband, which is tectonically mixed with rocks of the Southern Frame, and are thrust on the overturned southern flank of the broad Aghdarband Syncline (see chapter 6, "Structure", and Plate 2, sections 1 and 2).

3.2. The Triassic Aghdarband Group

The fossiliferous Triassic rock-sequence exposed in the Aghdarband Window was regarded originally as one formation, termed Aghdarband Formation (A. RUTTNER, 1984). The authors of this volume have now agreed to differentiate between four formations in accordance with both their specific lithology and paleontological contents, and to include these four formations in the Aghdarband Group. These formations are

1) The Sefid Kuh limestone Formation.
2) The Nazarkardeh Formation.
3) The Sina volcanic Formation.
4) The Miankuhi shale Formation.

3.2.1. Sefid Kuh Limestone Formation

(Nos. 21 and 22 [lower part of "Member 1"] on the geological map, Plate 1)

The most complete section of this lowermost formation of the Aghdarband Group is that of the steep western and northwestern face of Sefid Kuh, about three kilometers WNW of the northwestern corner of the mapped area (cf. Fig. 1). J. STÖCKLIN measured an overall section in 1972; A. BAUD and R. BRANDNER made detailed studies in 1972 and 1979 respectively in roughly the same place. The section presented now by A. BAUD, R. BRANDNER & D. A. DONOFRIO may serve for the type section of the Formation.

Fig. 6.
Sefid Kuh, view from the west.
Qgh = Qara Geheitan conglomerate; x = site of Fig. 9.

Fig. 7.
Sefid Kuh, view from the east.

Fig. 8.
Sefid Kuh Limestone, cross-bedded calc-arenite.
Boulder at the western foot of Sefid Kuh.

The present writer regrets that, due to the absence of accurate maps and lack of time, the Sefid Kuh area could not be included in the detailed mapping; he was only able to pay a few visits to this western area.

A short section was measured by him at the foot of the western face of Sefid Kuh, close to Qara Gheitan, and a few samples were collected from the base and from the top of the limestone.

The limestone of Sefid Kuh is part of the Aghdarband Syncline (Fig. 6). Corresponding to the ESE-plunging fold-axes in this area, the bottom of the Syncline crops out to the surface there; for this reason the limestone of Sefid Kuh has the shape of an oval dish (Fig. 7) with its axis inclined towards the east (ESE). According to the measurements of STÖCKLIN, BAUD and BRANDNER the total thickness of the limestone there is about 200 meters.

A characteristic feature of the limestone is an alteration of thick (meter) bedded to massive yellowish limestone and thin (centimeter to decimeter) bedded limestone light grey to bluish-grey in colour; the latter is partly nodular and frequently shows vermiculated features. Layers of cross-bedded calcarenite close to the base of the limestone accentuate the shallow water character of the limestone (Fig. 8).

BAUD, BRANDNER & DONOFRIO (this vol.) consider the whole rock sequence of the Sefid Kuh limestone Formation to be

" ... the product of a transgression-regression cycle ... "

They distinguish the sequence into four subunits, each of them representing a distinct pattern caused by the fluctuating depositional conditions. For details confer the columnar sections, i. e. Figs. 2 and 3, of their contribution.

A dark green to black coarse grained volcanic sandstone and a black conglomerate with pebbles not larger than 2–3 centimeters in diameter crop out at the very base of the limestone (Fig. 9). A sample (No. 76/93/10) collected from the top of this volcanic sandstone

" ... consists of well sorted grains of volcanic rocks with trachytic textures, pumiceous vitric fragments and crystals of plagioclase (albite) and subordinate quartz in a celadonite matrix: the composition is andesitic ... " (A. BAUD, G. STAMPFLI et al., this vol.).

This volcaniclastic bed is about 15 meters thick. Its contact with the overlying above mentioned calcarenite is a quick transition:

" ... The siliciclastic sedimentation changes to a pure carbonatic sedimentation within three meters. This transition is marked by an interbedding of tempestites with thin bedded silty marls" (BAUD, BRANDNER & DONOFRIO, this vol.).

Consequently, these volcaniclastics are included in subunit A of the Sefid Kuh limestone Formation at its basal part.

Unfortunately, the contact of these volcaniclastics with the underlying red conglomerate and sandstone of the Qara Gheitan formation (i.e. the top of the latter) is

Fig. 9.
Sefid Kuh Limestone, basal part.
C = black volcanic sandstone and conglomerate underlying the limestone.

coverd by rockfall talus at the foot of the west wall of Sefid Kuh. The kind of contact between Sefid Kuh limestone Formation and Qara Gheitan formation is disputed for this reason. The present writer – and with him also J. STÖCKLIN and A. BAUD see a slight angular unconformity between the bedding planes of the two formations. J. EFTEKHARNEZHAD & A. BEHROOZI as well as R. BRANDNER, however, deny such an unconformity. The former report from the area of Mazareh-e-Shahtut (situated to the southeast of the mapped area) a "green tuffaceous facies" of the upper part of the Qara Gheitan formation which changes to a vermiculated limestone of the Sefid Kuh Formation. This is in favour of BRANDNER's view which considers the Sefid Kuh Limestone to be the

" ... terminal member of a partly extremely thick stratigraphical sequence which is called 'Hercynian Molasse' in the area to the north of the Northern Iranian oceanic suture zone ... "

The top of the Sefid Kuh limestone Formation is formed by a

" ... thick-bedded to massive, cliff-forming, light coloured limestone ... "

(subunit D) with indications of emersion on its top (A. BAUD, R. BRANDNER & D. DONOFRIO, this vol.). It is overlain by a thin-bedded cherty limestone which is part of the Nazarkardeh Formation.

The age of the Sefid Kuh limestone Formation is well established. D. DONOFRIO recognized the conodonts

Neospathodus triangularis (BENDER) 1967
Ellisonia torta SWEET 1970
Ellisonia cf. *deliculata* SWEET 1970

in a sample collected about ten meters above the base of the limestone (No. 76/93/1; see Figs. 2 and 3 in BAUD, BRANDNER & DONOFRIO, this vol.). This indicates a Late Scythian (Spathian) age of basal parts of the limestone. In the middle segment of the type section

Ellisonia triassica MÜLLER 1956

found in sample No. 76/92 (subunit C of the Formation) still proves a Spathian age. On the other hand, conodonts of the cherty limestone overlying subunit D of the formation point to an Early Anisian age (Aegean/Bithynian) of the basal beds of the Nazarkardeh Formation. So, the whole Sefid Kuh limestone Formation is Late Scythian (Spathian) in age.

Besides the conodonts mentioned above, D. DONOFRIO found some samples of the Sefid Kuh limestone Formation to contain algae, foraminifera, microgastropods, ostracods, echinoderms, and fish remains. Of special interest is the occurrence of calcareous algae (*Acicularia* sp.) in the thick-bedded limestone of subunit D; according to BAUD, BRANDNER & DONOFRIO,

" ... this occurrence of dasycladacean algae is worldwide the earliest known after the Permo-Triassic event ... "

As only determinable megafossil collected in the scree below the western face of Sefid Kuh DONOFRIO notes

Eumorphotis sp.

Three major limestone bodies occur east of Sefid Kuh in the Aghdarband area proper. They are truncated by ESE-trending faults and represent – in each special case – mostly the upper part of the Sefid Kuh section only.

The southern narrow limestone strip at Miankuhi in the western part of the area (see map, Pl. 1) is the continuation of the northern limb of the Aghdarband Syncline, from Sefid Kuh to the east (Fig. 2, Slice II). Its anticlinal structure – well visible in the gorge of the Kal-e-Faqir valley, just outside of the map-area – disappears west of the Aghdarband village (P. 1208), forming the core of a well developed east-plunging anticline (Fig. 10). Rhynchonelloid brachiopods, collected in this limestone (sample No. 75/18), are described by M. SIBLÍK (this vol.) as

Costirhynchopsis ruttneri n. sp.

The northern limestone range at Miankuhi is a duplication of the southern range, due to folding and – partly – faulting (Slice I; see also sections 2 and 3 in Pl. 2). It is bounded to the north by the Northern Main Fault, but shows a transition to the Sina volcanic Formation through the Nazarkardeh Formation at the southern slope of the range (cf. chapter 3.2.2.).

A third limestone range reaches from the area south of tunnel "Sina" eastward beyond the mapped area as far as the village Ghal'eh Qabri (see Fig. 1); the ruins of a fortress west of that village mark the easternmost end of this limestone, which is unconformably overlain there by the Rhaethian Ghal'eh Qabri Shales (chapter 3.2.1.). This limestone ist the front of the thrust sheet

Fig. 10.
Miankuhi, view towards north.
→ = Anticline of Sefid Kuh Limestone, plunging towards east ("Aghdarband Anticline"); LA = volcanic litharenite (Sina Formation, top of the Shale Member).
In the background the Jurassic–Cretaceous coverbeds of the erosional Window of Aghdarband.

Slice III. Its anticlinal structure is well exposed in the gorge of the Kal-e-Anabeh valley (cf. Fig. 48), south of tunnel "Sina", and also farther to the east in the gorge west of Gal'eh Qabri.

Finally, several slices of limestone mark the overturned and sheared southern limb of the Aghdarband Syncline along the Southern Thrust Fault.

The limestone shows a similar appearance wherever it is exposed in the mapped area: it is light yellowish at the weathered surface, but light grey to grey, sometimes bluish-grey in colour when hammered. Massive beds alternate with thin-bedded layers, the latter partly marly and/or showing a type of undulation. Worm tubes are often found, especially in the southern limestone strip of Miankuhi. Basically, it resembles the limestone of the Sefid Kuh section, as shown by A. BAUD, R. BRANDNER & D. DONOFRIO (this vol.).

The position of the Sefid Kuh Limestone between the volcaniclastics at its base and the volcaniclastics of the Sina Formation induced J. EFTEKHARNEZHAD & A. BEHROOZI to suggest that the limestone bodies may have been local lenticular calcareous deposits beween volcanogenic sediments from the beginning. However, there is, in all probability, a gap in sedimentation below the volcaniclastics of the Sina Formation which covers late Anisian and early Ladinian times (cf. chapters 3.2.2. and 3.2.3.). It is possible that parts of both, the Nazarkardeh and the Sefid Kuh Formation were eroded during these times; nevertheless, the recent shape of the limestone bodies is most certainly the result of tectonic displacements.

R. BRANDNER (in BAUD, BRANDNER & DONOFRIO, this vol.) sees the facies-changes within the Sefid Kuh limestone sequence to be the result of eustatic sea-level fluctuations which took place in the whole western Tethys realm at Scythian times, i. e. in the area extending from Aghdarband via the Alborz Mountains to the Southern Alps. The main transgression at the base of the Sefid Kuh Limestone is equated by him with the Val Badia transgression known from the latter.

3.2.2. Nazarkardeh Formation

(Nos. 18 and 19 [upper part of "Member 1"] on the geological map, Pl. 1)

The type section of the Sefid Kuh limestone Formation (BAUD, BRANDNER & DONOFRIO, this vol., Fig. 2) shows on top of the thick-bedded limestone of subunit D a thin-bedded cherty limestone which yielded – besides of foraminifers, spicules, microgastropods, ostracods, echinoderms and fish-remains – the conodont

Gondolella bulgarica (BUDUROV & STEFANOV, 1975)

which points to an Early Anisian (Aegean/Bithynian) age of this limestone bed.

At the southeastern slope of the mountain Sefid Kuh (still outside of the mapped area) this cherty limestone is overlain by a nodular limestone which is interbedded with tuffaceous marl, shale and/or sandstone (Fig. 11). In this sequence the Bithynian ammonite

Pseudohollandites n. gen. *eurasiaticus* n. sp.

was found (KRYSTYN & TATZREITER, this vol.; foss. locality No. Agh 75/23b).

This alternating ammonite bearing sequence of beds is exposed also within the mapped area at two localities where the primary contact to the Sefid Kuh

Fig. 11.
Nazarkardeh Formation; eastern slope of Sefid Kuh.
SM = Sandstone Member of the Sina Formation (red volcanic sandstone).

Limestone is preserved; it was named there "Fossil Horizon 1" (RUTTNER, 1983 and 1984). One of these localities is a strip, two kilometers in length, exposed WNW of the Aghdarband village on the southern slope of the northern limestone range of Miankuhi (fossil localities Nos. 75/08, 75/25, 75/26); the second one was found in the easternmost part of the mapped area at both sides of the Kal-e-Anabeh valley, to the southeast of Tunnel Sina of the coal mine (fossil locality No. Agh 75/37).

R. BRANDNER found this fossiliferous sequence also on the southern slope of the southern limestone range of Miankuhi (cf. stratigraphic section No. 11, Fig. 26b).

The alternate carbonatic-tuffaceous bedding was previously considered to represent the transition from the Sefid Kuh Limestone to the volcaniclastics of the overlying Sina Formation (RUTTNER, 1983, 1984; cf. also the geological map Pl. 1). However, the sporadic occurrence of a monolithic limestone-conglomerate at the base of the Sina Formation suggests an erosional phase there. Furthermore, the wealth of ammonites found in these beds, and their paleontological significance justifies the establishment of a particular formation, as suggested by L. KRYSTYN, and to include in this formation also the cherty limestone found by BAUD, BRANDNER & DONOFRIO on top of the Sefid Kuh Limestone section.

The name of the Formation is derived from Kuh-e-Nazarkardeh (P. 1328 on the geological map Plate 1), i.e. a mountain summit commanding the view all over the area and situated 1.5 kilometers to the WNW of the Aghdarband village. The Formation is well exposed at the southwestern flank of this mountain range. There, the Nazarkardeh Formation varies in thickness between 20 and about 50 meters. It may interfinger with – or may have been folded in – the underlying bedded limestone. Thin bands of greenish coloured tuffaceous shale and sandstone between the limestone beds become gradually thicker upwards; the interbedded limestone is nodular, thin-bedded, greenish-grey or bluish grey in colour, partly oolithic and siliceous to varying degrees. Finally – on top of this alternating sequence – the whole rock consists mainly of volcanic material. This observation creates the impression of a transition into the adjoining Sina Formation.

The age of the Formation is Early Anisian, i. e. Aegean/Bithynian with respect of the basal cherty limestone (BAUD, BRANDNER & DONOFRIO) and Bithynian with respect of the ammonite bearing alternating carbonatic-tuffaceous beds (Fossil Horizon 1). In the former D. DONOFRIO found the indicative conodont *Gondolella bulgarica*; in the latter L. KRYSTYN & F. TATZREITER identified two ammonite horizons of the Bithynian: the lower *Osmani*-zone with its key fossil *Nicomedites osmani* and the upper *Ismidicus*-zone, containing the marker fossil *Aghdarbandites* n. gen. *ismidicus* (formerly *Anagymnotoceras ismidiucm*). It is striking, however, that these two horizons have never been found together at one of the fossil locations mentioned above. The *Osmani*-zone seems only to be present in structural Slices I and II, whereas the *Ismidicus*-zone seems to be confined to Slice III, which was overthrust from the South onto Slice II (see Fig. 2).

In detail the following ammonites were identified and described by L. KRYSTYN & F. TATZREITER (this vol.).

Structural Slice I
North of Mianhkuhi, *Osmani*-zone:
Fossil locality No. 75/08 (collected from the uppermost limestone-layer):
Nicomedites osmani TOULA, 1896
Pseudohollandites n. gen. *eurasiaticus* n. sp.
Gymnites aghdarbandensis n. sp.
Costigymnites n. gen. *asiaticus* n. sp.
Procladiscites cf. *proponticus* TOULA 1896
Fossil locality No. 75/25:
Nicomedites osmani, TOULA 1896
Pseudohollandites sp.
Leiophyllites suessi (MOJSISOVICS, 1882)

Structural Slice II
Sefid Kuh, SE-slope, *Osmani*-zone:
Fossil locality 75/23b
Pseudohollandites n. gen. *eurasiaticus* n. sp.

Structural Slice III
Kal-e-Anabeh valley, *Ismidicus*-zone:
Fossil locality No. 75/37
Aghdarbandites n. gen. *ismidicus* (ARTHABER, 1915)
Semibeyrichites n. gen. *ruttneri* n. sp.
Gymnites asseretoi TOZER, 1972
"Japonites" cf. *kirata* DIENER, 1907
Sturia sansovinii (MOJSISOVICS, 1869)
Costigymnites n. gen. *asiaticus* n. sp.
Procladiscites cf. *proponticus* TOULA, 1896
Psilosturia sp.

Sturia sansovinii was also found in a tectonically disturbed zone east of the Aghdarband village (fossil locality No. 28a).

Treated as a whole, the "*Nicomedites* Association" of both Bithynian ammonite horizons (L. KRYSTYN & F. TATZREITER; this vol.) characterizes faunistically the Early Anisian North-Tethyan sub-province; according to L. KRYSTYN this peculiar fauna can be traced from Gebze (Kokaeli Peninsula, western Turkey) around the southern edge of Triassic Laurasia till eastern Sibiria (see Figs. 3 and 4 in the paper mentioned above).

A few brachiopodes were collected in the Nazarkardeh Formation; these were determined and described by M. SIBLÍK (this vol.) and are as follows:

Punctospirella aff. *fragilis* (SCHLOTHEIM, 1884)

collected at fossil locality No. 75/37 in the Kal-e-Anabeh valley, and the new species

Dareithyris vulgaris n. sp.

found in the Nazarkardeh Formation of Miankuhi (sample No. 75/26) as well as on top of the limestone of Sefid Kuh (sample No. 75/11), west of the mapped area.

A sample of volcanic arenite interbedded in pelagic limestone was petrographically analysed by A. BAUD et al. (this vol.); it contains lithic fragments of trachyte (sample No. 75/37).

3.2.3. Sina Volcanic Formation

(No. 10–17 ["Member 2" and "Member 3"] on the geological map, Plate 1)

Volcanic matter is the main component of the sequence of sandstones, shales and marls, which, being 400 to 700 meters thick, overlie the Sefid Kuh and Nazarkardeh Formations and form the Sina volcanic Formation. Tunnel "Sina" – the main tunnel for the eastern part of the coal field of Aghdarband – provides the name for the Formation as well as for the area where A. BAUD measured a stratigraphic section in that Formation.

Recent petrological investigations carried out by R. CAS and H. SARP on rock samples collected by the present author during the mapping campaign confirmed the prior opinion held by A. BAUD, G. STAMPFLI and D. STEEN, that all – or at least nearly all – rock types of the volcanic sequence in question are true sedimentary rocks deposited in a marine environment. Therefore – and in agreement with the authors mentioned above – such terms as "tuff" or "tuff-lava" (cf. the legend to the geological map, Plate 1) can no longer be used in this context.

The Formation is mostly composed of tuffaceous sandstone and tuffaceous shale with intercalations of tuffaceous limestone, marlstone and marl. A few layers of conglomerate are also interbedded. Sole markings on bedding planes and graded bedding impart some sandstone beds with flysch-like features.

According to A. BAUD et al. (this vol.) the volcaniclasts as well as the mineral assemblage in the sandstone beds point to an intermediate (andesitic or trachy-andesitic) to acidic (trachydacitic, even rhyolitic) volcanism in the source area. A general trend of increasing acidity upwards can be observed within the Formation.

The lithofacies of the Formation varies somewhat laterally in the mapped area. Moreover, intensive folding and faulting is a considerable impediment to the establishment of a representative section through the Formation. Only in the westernmost part of the area would it be possible to measure such a complete section, that is in the flexure of the main Aghdarband Syncline at the SE slope of Sefid Kuh (W of the mapped area) and in the region between Kal-e-Faqir and the tributaries of Kal-e-Bast. Unfortunately, a final field campaign, in which it was intended to include the measurement of that section, could not be realized because of political reasons.

However, there is on hand the Sina cross-section of the easternmost part of the area, measured by A. BAUD (stratigraphic sections 9–8, 5, 4–3, 2 and 1 on the geological map, Plate 1), which was studied in detail by G. STAMPFLI and D. STEEN (A. BAUD et al., this vol.). Although this section is incomplete, as it was measured partly in Slices I+II and partly in Slice III, it gives an instructive petrological picture of the Formation. A second section was measured by R. BRANDNER 2.75 kilometers farther west in Slice I (stratigraphic section No. 10) and a third one was measured by the same author still 3.6 kilometers farther to the west in Slice II of the Miankuhi region (stratigraphic section No. 11). A petrological analysis kindly arranged through A. BAUD was done by P. CAS and H. SARP on a few samples collected by the writer; their work is herewith gratefully acknowledged.

Two lithological units, now defined as members of the Sina Formation, can be distinguished, in the field as well as on the map (Plate 1):

- Tuffaceous Shale Member ("Member 3" on the map).
- Tuffaceous Sandstone Member ("Member 2" on the map).

The fossiliferous Faqir Marl Bed ("Fossil Horizon 2") is now considered to be the base of the tuffaceous Shale Member.

At present, a reliable age is established only for the upper Shale Member. The ammonite (*Romanites*) fauna of the Faqir Marl Bed indicates a Late Ladinian age (Longobardian 3) for the base of the Member (KRYSTYN & TATZREITER, this vol.); radiolarians and spicules of poriferans found in a siliceous limestone on top of the Member point to an Early Carnian (Late Cordevolian) age (D. DONOFRIO, this vol.). Thus, the tuffaceous Shale Member of the Sina Formation covers the startigraphic range Latest Ladinian to Earliest Carnian.

The time-rock span of the tuffaceous Sandstone Member, however, is not so well known yet. Findings of *Daonella lommeli* in the sandstone below the Faquir Marl Bed (samples Nos. 75/22b, 75/56) suggest that at least the upper part of the Member is still Late Ladinian in age. With regard to the base of the Member (and of the Sina Formation on the whole) we are still in the dark. The only indication of Lower Ladinian (or/and Upper Anisian respectively) are finds of conodonts (*Gondolella mombergensis* and *G. constricta*) recently made by D. DONOFRIO in lower parts of the stratigraphic section No. 10 R. BRANDNER's (cf. Fig. 12a). These finds question the existence of a major gap of sedimentation between the Nazarkardeh and Sina Formations as previously suspected (e.g. p. 139 and p. 142, this volume).

3.2.3.1. Tuffaceous Sandstone Member

(Nos. 15, 16, 17 and 20 ["Member 2" + No. 20] on the geological map, Plate 1)

Outcrops of a monomictic limestone-conglomerate at the very base of the Sina Formation favour the assumption mentioned above. This conglomerate (No. 20 on the geological map) was previously considered to belong to the Nazarkardeh Formation. It was found at the eastern side of the Kal-e-Anabeh valley (structural Slice III) overlying partly the Nazarkardeh and partly the Sefid Kuh Limestone Formations and it crops out also in the gorge of the Kal-e-Faqir (mis-spelled "Kal-e-Fagig" on the map, Plate 1) valley (structural Slice II) outside (NW) of the mapped area, resting there on Sefid Kuh Limestone. However, this conglomerate is missing at Miankuhi along the outcrops of the Nazarkardeh Formation; there, the Nazarkardeh Formation grades upwards into the Sandstone Member of the Sina Formation.

The well rounded but unsorted pebbles of the conglomerate are up to 10 centimeters in diameter and consist solely of Sefid Kuh Limestone. The overlap of the conglomerate on Sefid Kuh limestone as well as on beds of the Nazarkardeh Formation suggests the existence of an erosional period before the accumulation of the volcanogenic material of the Sina Formation. Such a period of erosion may also explain partly the "gappy" occurrence of the Nazarkardeh Formation in the Aghdarband area.

However, the duration of this period of erosion is confined by the above mentioned finds of Late Anisian to Early Ladinian conodonts in the Sandstone Member of the stratigraphic section No. 10 (cf. Fig. 12a); it is also restricted locally to places where the Nazarkardeh and Sefid Kuh limestone Formations were exposed to erosion. Obviously, this erosional phase was the result of a tectonic unrest in connection with the incipient volcanic activity, probably in Late Anisian times.

The principal rock of the Member is a well-bedded tuffaceous sandstone (centimeter to decimeter bedding); varying amounts of shale, calcareous shale, marlstone and even limestone are interbedded in the sandstone. In the field, the main colour of the Sandstone Member is green (greenish-grey to bright green); however, other colours, such as red or violet may occur also. The top of the Member consists of a hard, massive, dark green coloured volcanic litharenite (No. 16 on the geological map). This is the footwall of the fossiliferous Faqir Marl Bed ("Fossil Horizon 2"), which is the base of the Shale Member of the Sina Formation. The litharenite forms conspicuous cliffs in the landscape.

There are some differences in detail in the lithofacies between the Structural Slices I+II and Structural Slice III (see also chapter 3.2.3.2. and columnar sections, Fig. 4).

Structural Slices I+II

The lithofacies of the Sandstone Member is very similar in both slices; in Slice I this Member is truncated by faults, as is the Member in Slice II in the Miankuhi region, but it is complete in the central part of Slice II, that is in the broad flexure of the Aghdarband Syncline at both sides of the Faquir valley and on the SE slope of Sefid Kuh in the extreme west of the area.

The northern part of the Sina cross-section, measured by A. BAUD in the eastern part of the mapped area (Stratigraphic Sections 9 and 8), illustrates the composition of a – rather basal – portion of the Sandstone Member in Slice I (A. BAUD et al., this vol., Figs. 2 and 3). Andesitic volcano-arenites (partly microconglomerates) grade to trachy-andesitic to trachytic ones near the top of the section; they are interbedded with fossiliferous tuffaceous lime-packstone. The fossils collected by A. BAUD (brachiopods, *Daonella* sp., crinoids) are stored at Tehran and, as they are inaccessible at present, have not been determined.

BAUD distinguishes a reddish-coloured lower volcano-sedimentary unit and an upper green-coloured unit, the green colour of the latter being due to the presence of chlorite.

The reddish coloured unit 1 (A. BAUD) can certainly be assigned to Slice I and very probably represents a basal part of the Sandstone Member; a similar sequence of reddish-coloured tuffaceous beds was observed by the present writer on the SE-slope of Sefid Kuh (Slice II), overlying there the fossiliferous Nazarkardeh Formation (cf. Fig. 11). Indications that the volcanic material (ash, crystal tuff, lithic tuff, lapilli) was transported by density currents are pointed out by BAUD.

The structural position of the green coloured unit 2 is ambiguous. Unfortunately, the fault separating Slice I and Slice II is not clearly recognizable in the Sina region; the fault may run possibly in the valley west of tunnel "Sina" being covered there by alluvial fill. In that case, unit 2 of the Sina cross-section (stratigraphic section 8) – or part of it – would belong to Slice II and could not be considered to be the normal stratigraphic continuation of unit 1 (see Figs. 2 and 3 in A. BAUD et al., this vol.). But in any case the occurrence of *Daonella* sp. in the upper part of unit 2 points to a stratigraphically rather high position of that unit within the Sandstone Member.

Tuffaceous rocks similar to those of unit 1 and unit 2 are exposed east of the Sina cross-section (beyond the mapped area) on both sides of the Ghal'eh Qabri valley

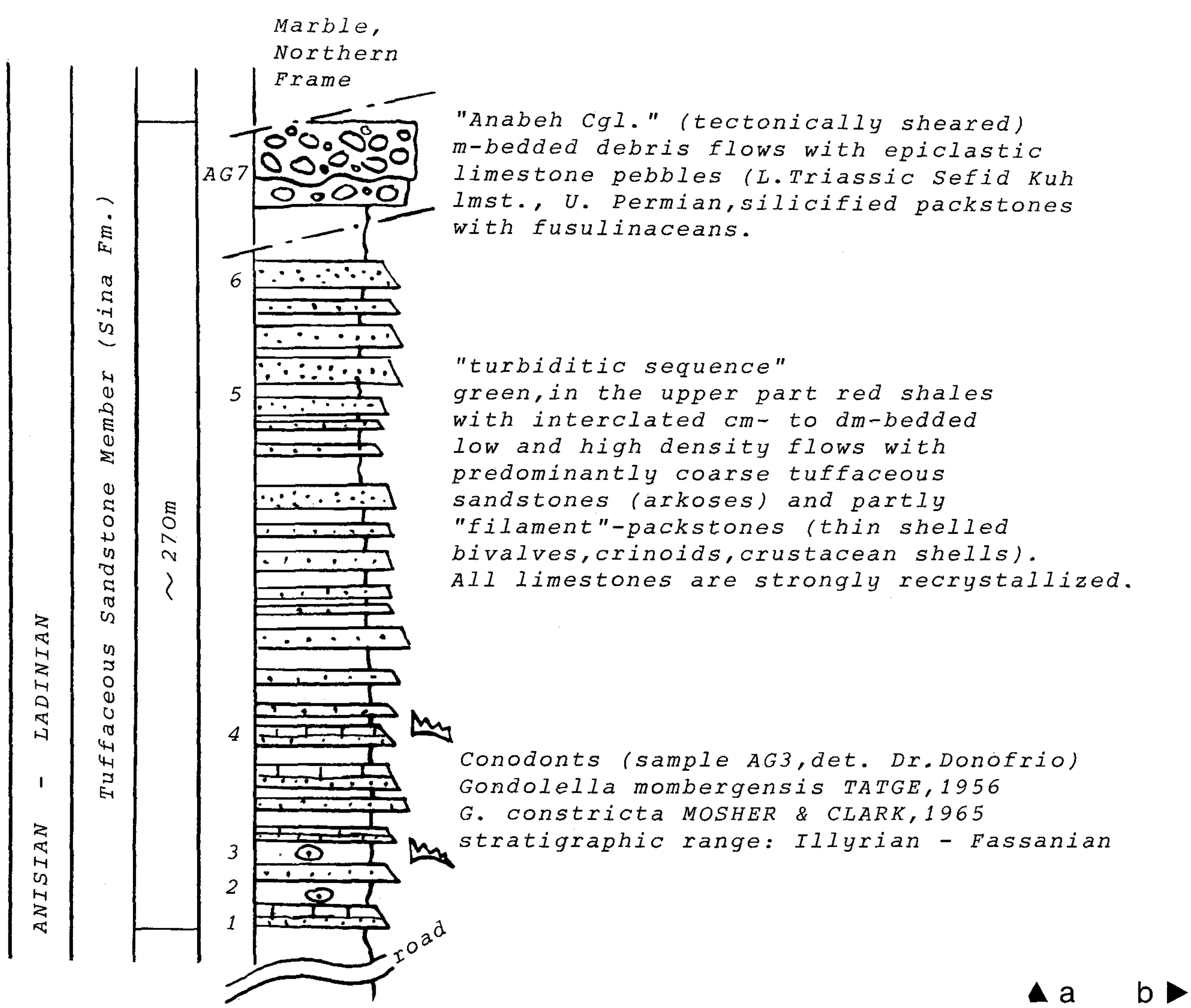
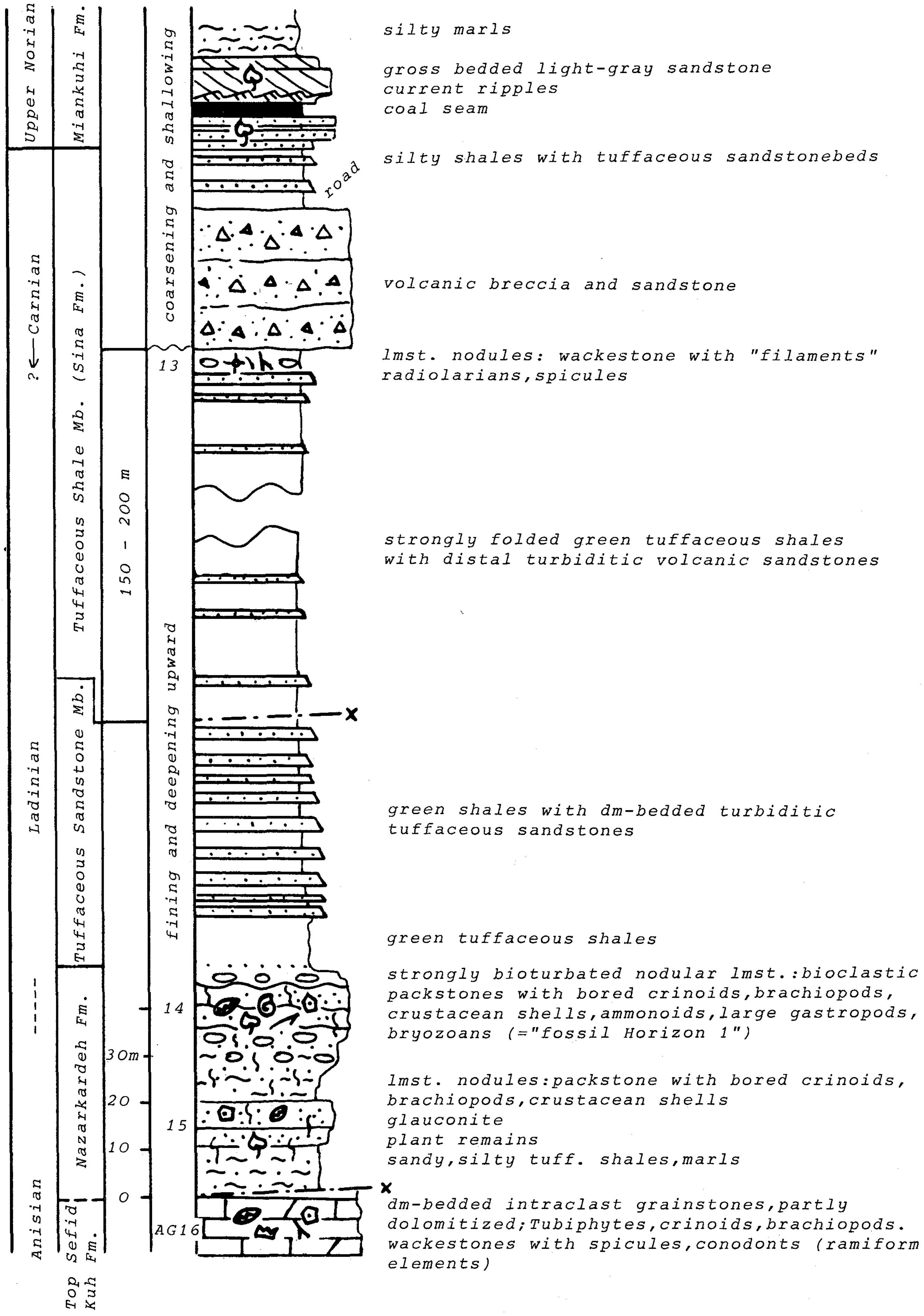


Fig. 12.
Sina volcanic Formation.
a) Stratigraphic Section No. 10, measured by R. BRANDNER 600 m east of the Aghdarband village (cf. geological map, Plate 1). Extremely folded in part (see Diagram D_1, chapter 7.2.); synoptical section, thickness approximately quoted.
b) Stratigraphic Section No. 11, measured in Slice II, 2.8 km WNW of the Aghdarband village (Miankuhi); cf. Structural Sections No. 2, Plate 2, and B'–B, Plate 4, respectively.


Upper Norian
?←Carnian
Ladinian
Anisian
Miankuhi Fm.
Tuffaceous Shale Mb. (Sina Fm.)
Tuffaceous Sandstone Mb.
Nazarkardeh Fm.
Sefid Kuh Fm.
Top
150 - 200 m
30m
20
10
0
coarsening and shallowing
fining and deepening upward
13
14
15
AG16
road
silty marls
gross bedded light-gray sandstone
current ripples
coal seam
silty shales with tuffaceous sandstonebeds
volcanic breccia and sandstone
lmst. nodules: wackestone with "filaments"
radiolarians,spicules
strongly folded green tuffaceous shales
with distal turbiditic volcanic sandstones
green shales with dm-bedded turbiditic
tuffaceous sandstones
green tuffaceous shales
strongly bioturbated nodular lmst.:bioclastic
packstones with bored crinoids,brachiopods,
crustacean shells,ammonoids,large gastropods,
bryozoans (="fossil Horizon 1")
lmst. nodules:packstone with bored crinoids,
brachiopods,crustacean shells
glauconite
plant remains
sandy,silty tuff. shales,marls
dm-bedded intraclast grainstones,partly
dolomitized;Tubiphytes,crinoids,brachiopods.
wackestones with spicules,conodonts (ramiform
elements)

between the limestone of Slice III and the Northern Main Fault (Fig. 2). The tuffaceous sandstone is partly coarse grained; it is well bedded mostly, but it also contains a few compact layers, each having thicknesses of more than one meter. Some of the beds display a strikingly bright green colour. The rocks are strongly faulted along the valley. This fault-zone contains tectonic inclusions of coal and coaly shale and is possibly the eastern continuation of the fault between the Slices I and II.

A further cross-section was measured by R. BRANDNER about 600 meters east of Aghdarband village, 2.75 kilometers west of the Sina cross-section (stratigraphic section 10 on the map). This section (Fig. 12a) crosses a part of the Sandstone Member of Slice I. The sandstone beds are intensively folded in the lower part of the section (see Diagram D_1, chapter 7.2.). A petrographic analysis of a coarse grained volcanic arenite (sample No. 76/74) collected 350 meters west of that section, is given by A. BAUD et al., chapter 4.2. The rock shows a low grade of anchimetamorphism.

Apart from this, the stratigraphic section No. 10 shows two pecularities: firstly the finds of conodonts in the lower part of the section and, secondly, the conglomerate northerly adjacent to the sandstone-shale sequence of the Sandstone Member. The conodonts represent the only indication of Late Anisian–Early Ladinian age in lower parts of the Sandstone Member so far; the conglomerate – shown to belong to the Qara Gheitan formation on the geological map, Plate 1) – is equalized by BRANDNER with the Anabeh Conglomerate found so far in Slice III only.

West of the Aghdarband valley, the fault between Slice II and Slice I runs right into a narrow syncline, which is squeezed and faulted between two limestone anticlines (Pl. 2, sections 3, 2, 1). The sandstone is mixed with shales there; slices of coaly shales and of conglomerate indicate the degree of deformation which occurred within that syncline. Three layers of hard vol-

Fig. 13.
Sina volcanic Formation; Kal-e-Bast.
SK = Sefid Kuh limestone Formation; Sina Formation: M_2 = Sandstone Member, M_3 = Shale Member; → = Faqir Marl Bed (fossil locality no. 79).

Fig. 14.
The Aghdarband Syncline seen from the west (from the eastern slope of Sefid Kuh).
NF = Nazarkardeh Formation; Sina Formation: M_2 = Sandstone Member, M_3 = Shale Member; LA = top litharenite of the Shale Member.

canic arenite could be traced on the map; they are, possibly, a tectonic repetition of one and the same bed.

South of this narrow syncline, i. e. along the northern flank of the Aghdarband Syncline, the Sandstone Member of Slice II is faulted (and folded) against the southern limestone anticline north of Miankuhi (see Pl. 2, cross-sections 3 to 1); only parts of the Member are exposed there (Fig. 13). Stratigraphic section No. 11 measured there by R. BRANDNER (Fig. 12b) shows the reduced thickness of the Sandstone Member. However, BRANDNER could trace the Nazarkardeh Formation, about 50 meters thick, at the boundary to the Sefid Kuh Limestone even there – in spite of the strong tectonical deformations. But further west – i.e. mostly beyond the mapped area – the complete rock sequence of the Member is exposed in the broad flexure of the main Aghdarband Syncline (Fig. 14).

It is highly regrettable that no cross-section was studied there in order to serve as a type section and for comparison with the sections as measured by A. BAUD and R. BRANDNER in tectonically disturbed areas east and west of the Aghdarband village. However, the present writers' fieldbook notes the same types of rocks as described in detail for the Sina cross-section, i.e. tuffaceous sandstone, fine to coarse grained, greenish-grey to green, generally well bedded, with shaly and/or calcareous intercalations. At the base of the Member (SE slope of Sefid Kuh) the prevailing colours of the rocks are reddish or brownish.

The top of the Sandstone Member is a conspicuous and mappable layer, consisting of a dark green-coloured, hard and massive sandstone (litharenite, No. 16 on the geological map), which forms the footwall of the multicoloured Faqir Marl Bed at the base of the Shale Member. A sample of this litharenite collected at the very top of the Member, right below the Faqir Marls at fossil locality No. 86 (east of the Kal-e-Bast valley), is described as

" ... tuffaceous sublitharenitic limestone ... "

containing lithic fragments, which consist of

" ... flow-banded lightly viscous magmas of both dacitic and trachitic composition ... " (A. BAUD et al., this vol., chapter 4.2.).

The thickness of that layer varies from 5 to 20 meters; the hard and compact rock forms conspicuous ridges and escarpments in the terrain.

Fossil remnants are found scattered in the tuffaceous beds of the Member, both in Slice I and in Slice II. These are shells and casts of brachiopods, pelecipods and small gastropods, as well as crinoid stems, but they are mostly undeterminable.

Fragments of *Daonella* sp. occur in the upper part of the Member (cf. geological sketch map, Fig. 2) among these fossil remnants. In two of these samples they were proven by L. KRYSTYN to be classified as

Daonella lommeli (WISSMANN 1841).

Both fossil localites are situated very closely below the top-litharenite of the Member (cf. geological sketch map, Fig. 2). Sample No. 76/56 was collected together with *Monophyllites* sp. at the northwestern edge of the mapped area, between the two valleys Kal-e-Faqir and Kal-e-Bast – northwest of fossil locality No. 79 – below the litharenite bed, and sample No. 75/22b was found north of Miankuhi in the same position. The rock containing that fossil is described as

" ... pelagic skeletal tuffaceous lime-wackestone ... "

by A. BAUD et al. (chapter 4.2.) using sample No. 75/22b as reference material.

This proves a Late Ladinian age (?Longobardian 2) for the top of the Sandstone Member.

The sandstone beds frequently contain plant remains, especially close to the top of the Member. There, well preserved *Equisetum*-like stems were observed (Fig. 15). Samples of plant remains collected in this sandstone were indeterminable (e.g. sample No. 76/63, M. BOERSMA et al., this vol.).

Structural Slice III

The lithofacies of the Sandstone Member in this thrust sheet is illustrated in the southern part of A. BAUD's Sina cross-section, which represents nearly the complete Member from near base to the top (stratigraphic sections 5, 4, 3 and 2 on the geological map, Pl. 1; Fig. 5 in A. BAUD et al., this vol.).

True, the base of that part of the section is a fault against Sefid Kuh limestone Formation, but fossiliferous beds of the Nazarkardeh Formation are exposed

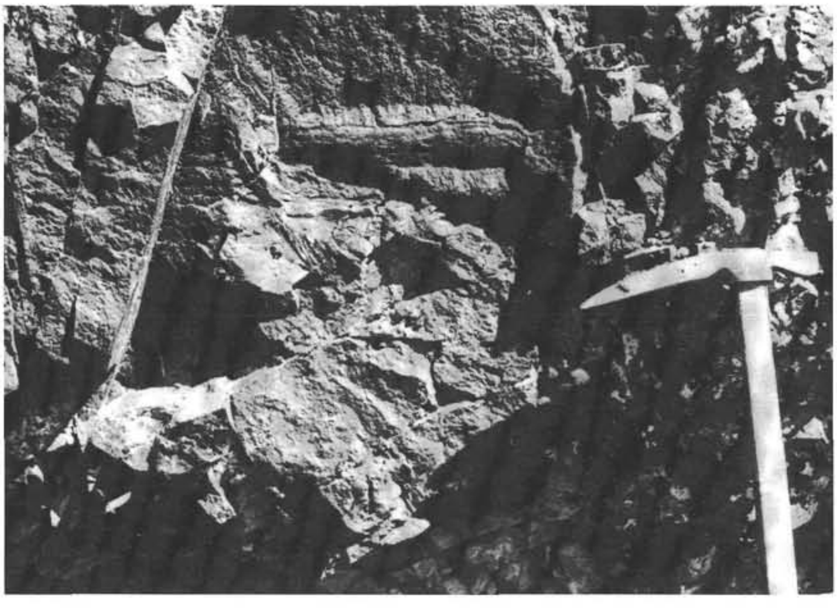


Fig. 15.
***Equisetum* sp. in Sandstone Member; Kal-e-Bast.**
Fossil locality No. 63.

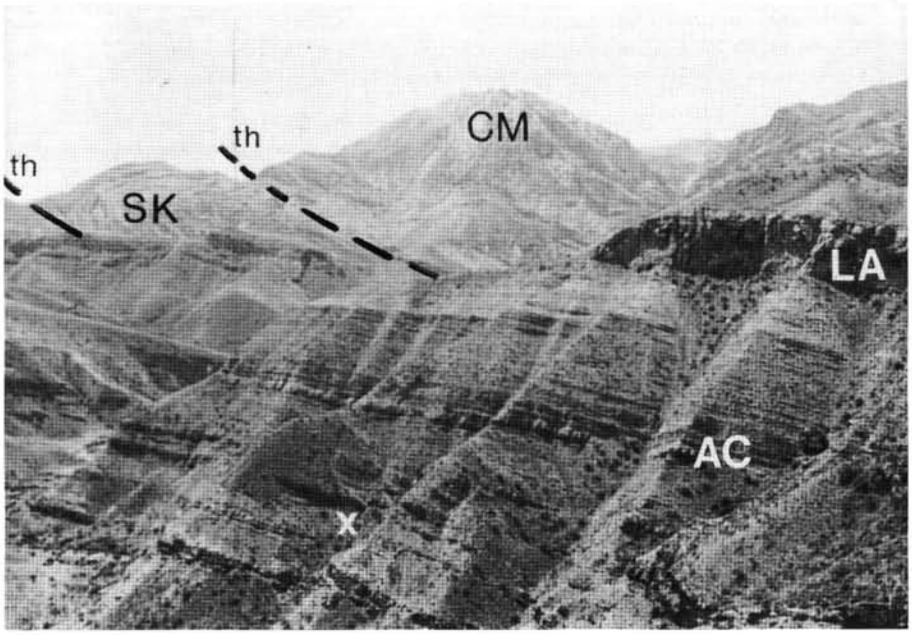


Fig. 16.
Sandstone Member of the Sina volcanic Formation; Kal-e-Anabeh, western slope.
AC = Anabeh Conglomerate; LA = top litharenite of the Sandstone Member; x = site of Sample no. 75/38.
In the background schuppenzone of the Southern Frame: SK = Sefid Kuh Limestone; CM = Carboniferous Limestone; th = thrust fault.

just east of the cross-section in Anabeh valley; therefore, not too much is supposedly missing there at the base of the section. A. BAUD distinguishes 5 subunits.

Subunit A

This basal subunit (ca. 100 meters) consists of alternate beds of volcanic sandstone and tuffaceous shale. Three layers of compact green coloured volcanic sandstone have been mapped by the present writer east of the cross-section on the western slope of the Kal-e-Anabeh valley, where the exposures of the subunit are more complete (Fig. 16). The shales between the sandstone layers are up to one meter thick and are green, grey or violet-red in colour. In a sample No. 75/38) of those violet-red shales R. OBERHAUSER found well preserved oospores of charaphyte (Fig. 17).

Subunit B – Anabeh Conglomerate

This conglomerate bed (No. 17 on the geological map, Pl. 1) is a marker bed in Slice III, but is not present in the structural Slices I and II. It is generally only a few meters thick and consists in the cross-section of two layers (2 m and 8 m) separated from each other by 5 meters of coarse grained sandstone. The bed is named after the Kal-e-Anabeh valley on account of its general significance. The conglomerate consists of

" ... well rounded pebbles up to 0,1 m in diameter in a matrix of well sorted litharenite, with felsic metamorphic fragments, chert,

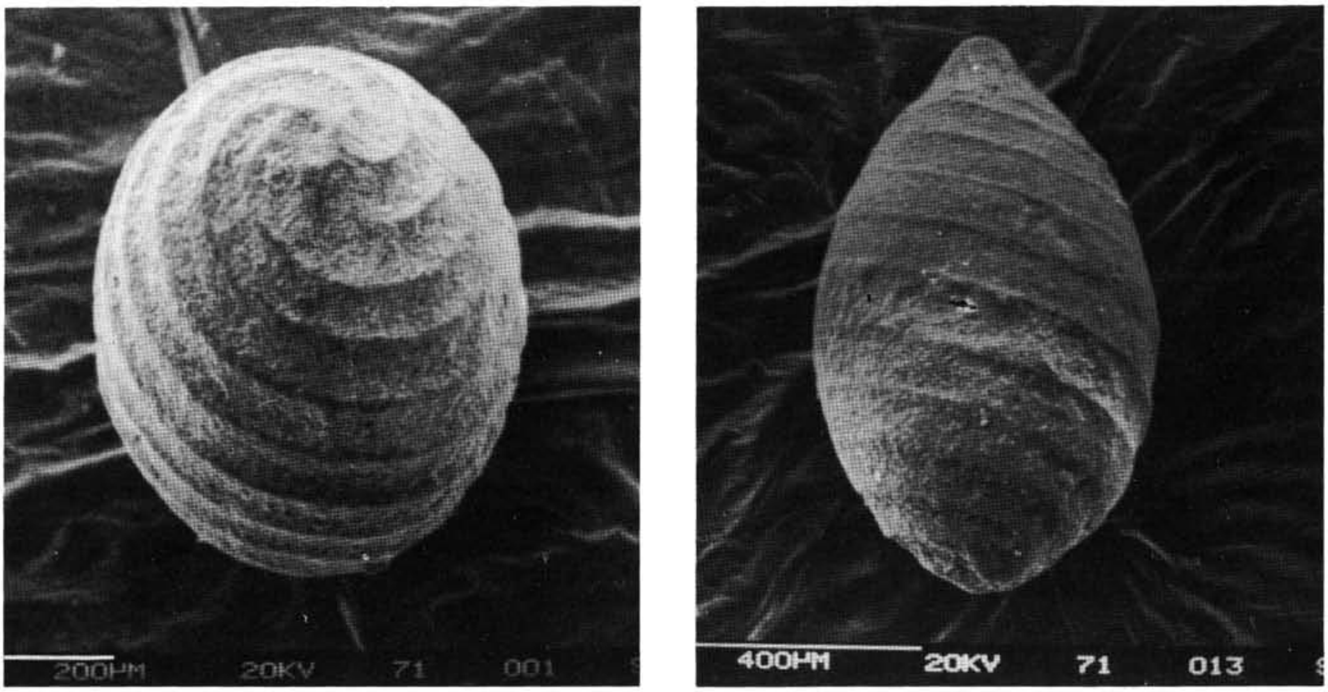


Fig. 17.
Oospore of a Charaphyte.
Sample no. 75/38, violet coloured shale intercalation of the Sandstone Member, western slope of Kal-e-Anabeh valley.
Phot. M. SCHMID.

granophyre, abundant quartz and rare calcitized felspars (microcline); the pebbles' composition includes very abundant bioclastic limestones, subordinate acid volcanic rocks and white quartzarenite ... " (A. BAUD et al., this vol.)

The present writer noted also green tuffite and white quartz. The pebbles are generally of walnut to fist size, exceptionally some limestone pebbles are up to 10 centimeters in diameter. A. BAUD identified limestone pebbles of middle Carboniferous, late and latest Permian and early Triassic age.

" *... The roundness of the pebbles and their composition suggest derivation from beaches or gravel bars adjacent to an uplifted crystalline basement with its late Paleozoic – early Triassic carbonate cover ...* " (A. BAUD et al., chapter 3.2.3., this vol.).

The present writer drew a parallel between this conglomerate bed, now named the Anabeh Conglomerate, and the conglomerates of the Baqoroq Formation of the Nakhlak Group in the Anarak region (A. RUTTNER, 1984).

Subunit C (ca. 40 meters)
is a fine-grained sandstone alternating with calcareous shale (partly red in colour) and tuffaceous limestone, the latter containing fragments of *Daonella* sp. Metamorphic felsic detritus mixed with volcaniclastics is recorded by A. BAUD et al.

Subunit D (ca. 160 meters)
consists predominantly of fine-grained calcareous and tuffaceous sandstone trachytic in composition with a "graded microconglomerate interbedded with coarse grained volcanic litharenite" (containing trachytic and rhyodacitic grains) at the base and crinoidal tuffaceous limestone on top. East and west of the cross-section, two layers of hard, dark green sandstone (litharenite) – thinning out laterally now and again – are shown on the geological map.

" *... Graded bedding, thinly laminated textures and sole marks indicate distal turbiditic deposits ...* " (A. BAUD et al., this vol.).

Subunit E (ca. 50 meters)
This subunit, finally, is the same thick bedded to massive, top-litharenite of the Member that exists in Slices I and II. However, its thickness is more than twice as much there and it is separated in most places from the overlying Faqir Marl Bed by a calcareous tuffaceous sandstone. According to A. BAUD et al., this litharenite contains rock fragments of trachydacitic composition in a chloritized matrix; tuffaceous crinoidal packstone is at the base of the Faqir Marl Bed. The litharenite forms conspicuous escarpments in the landscape south and southeast of tunnel "Sina".

*

On the whole, the Sandstone Member contains more multicoloured shale and more hard litharenite layers in structural Slice III than in the Slices I and II, and the essential Anabeh Conglomerate Bed is completely lacking in the latter. However, the trend of an upwards increasing acidity in the volcanic material is recognized in structural Slice III also, according to A. BAUD et al.

A similar succession of rocks is exposed farther west in Slice III, southeast of Aghdarband village, close to the Main Southern Overthrust.

3.2.3.2. Tuffaceous Shale Member

(Nos. 10, 11, 12, 13 and 14
["Fossil Horizon 2" + "Member 3"]
on the geological map Plate 1)

The upper part of the Sina Formation consists predominantly of tuffaceous shale; interbedded are layers of thinly bedded fine-grained sandstone and fossiliferous calcareous beds. The main colour in the field is dark green to greenish grey. At the surface the shales crumble to thin pencil-like bodies ("pencil shales"). At the base of the Member is a conspicuous key bed termed the Faqir Marl Bed; the top of the Member consists of a hard, dark green coloured litharenite, similar to that on top of the Sandstone Member. The estimated thickness of the Shale Member is 300–500 meters.

With regard to the shales encountered in the Sina cross-section, A. BAUD came to the following conclusion:

" *... Thin-bedded calcareous shale and marl with pelagic bivalves, sponge spicules and isolated crinoid stems suggest a distal, deep ramp environment ...* " (A. BAUD et al., this vol.).

The age ranges form Latest Ladinian (Longobardian 3) at the base to Early Carnian (Late Cordevolian) at the top of the Member.

The Faqir Marl Bed
("Fossil Horizon 2", No. 14 on the geological map)

The basal bed of the Shale Member is conspicuous in three ways:

a) Its pink and light green colour makes it stand out in the landscape.
b) As such it is an important marker bed over nearly the entire area.
c) It contains a wealth of megafossils and microfossils: cephalopods, brachiopods, pelecypods and crinoids as well as foraminifers and ostracods.

Its name is derived from Kal-e-Faqir, a valley situated at the northwestern edge of the mapped area, where the Bed is well exposed.

Lithologically the Bed consists of layers of marl, calcareous shale, tuffaceous marly limestone and tuffaceous calcareous sandstone. Since it is crossed by the Sina cross-section (strat. sections 3 and 1 on the map), it is described in detail by A. BAUD et al. (this vol., Fig. 5) and is characterized there in general as a "marly skeletal tuffaceous sandstone".

The underlying rock of the Faqir Marl Bed is the top-litharenite (No. 16 on the map) of the Sandstone Member. A sample from the base of the Faqir Marl Bed collected at Miankuhi in the western part of the area (sample No. 75/16) is described by A. BAUD et al. as

" *... pelagic tuffaceous skeletal lime packstone of mixed bioclastic and volcanoclastic origin ...* "

The average thickness of the Faqir Marl Bed is 20–25 meters.

A detailed section across the Faqir Marl Bed was measured by the present author in the vicinity of the Sina cross-section at fossil locality No. 36 (see Fig. 18). This section shows that specific types of megafossils are confined to specific layers within this Bed. The same is the case at fossil locality No. 79 in the western part of the area (see Fig. 19). The colour of the layers is alternatively grey, dark green, light green, pink and purple; but looking at the bed from afar, the general impression is of pink and light green coloration.

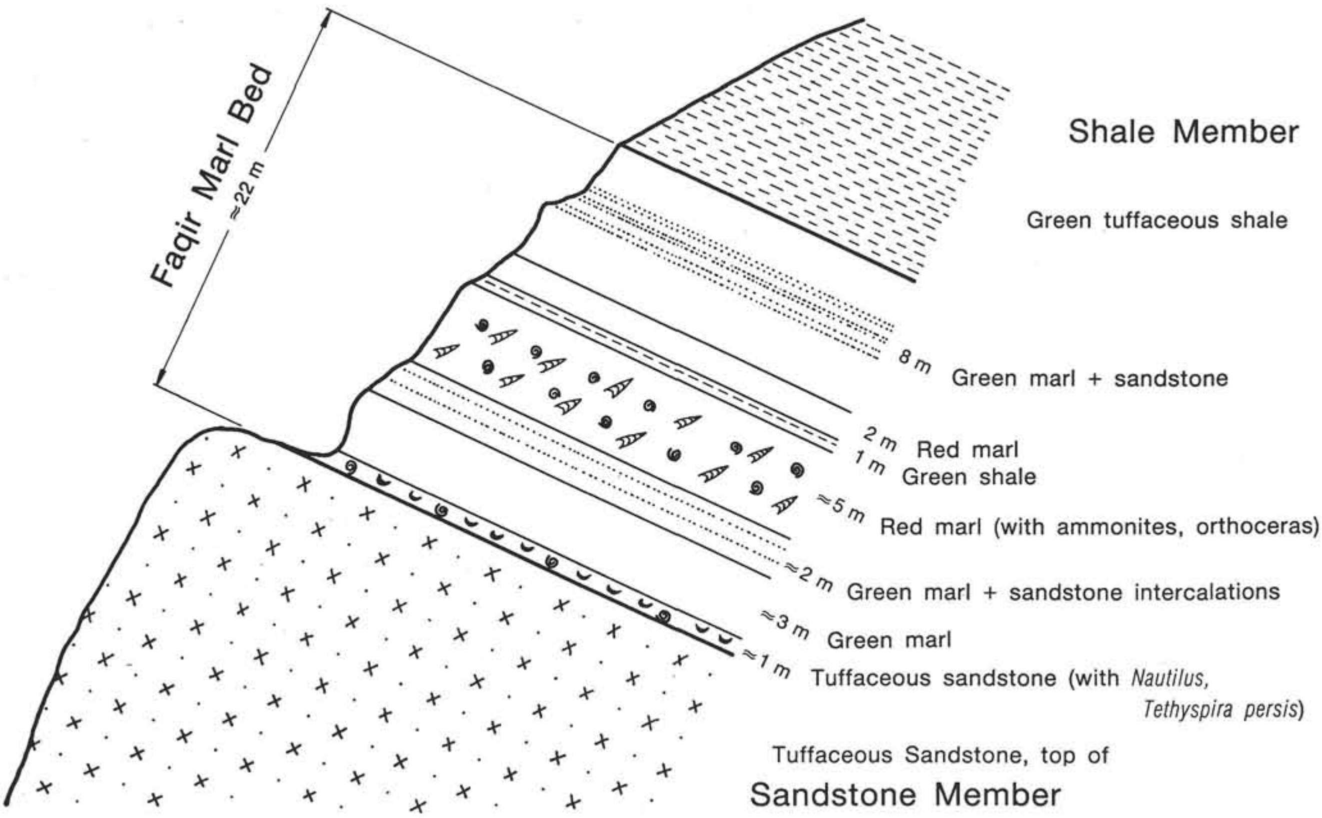


Fig. 18.
Faqir Marl Bed, detailed section.
Fossil locality No. 36, SW of Tunnel Sina (Sina-cross-section).

The fossils collected in the Faqir Marl Bed were examined and studied by E. KRISTAN-TOLLMANN, L. KRYSTYN & F. TATZREITER, R. OBERHAUSER and M. SIBLÍK; they are described in particular in the respective papers of the present volume. The following is a general outline of the fossils so far found in the Faqir Marl Bed.

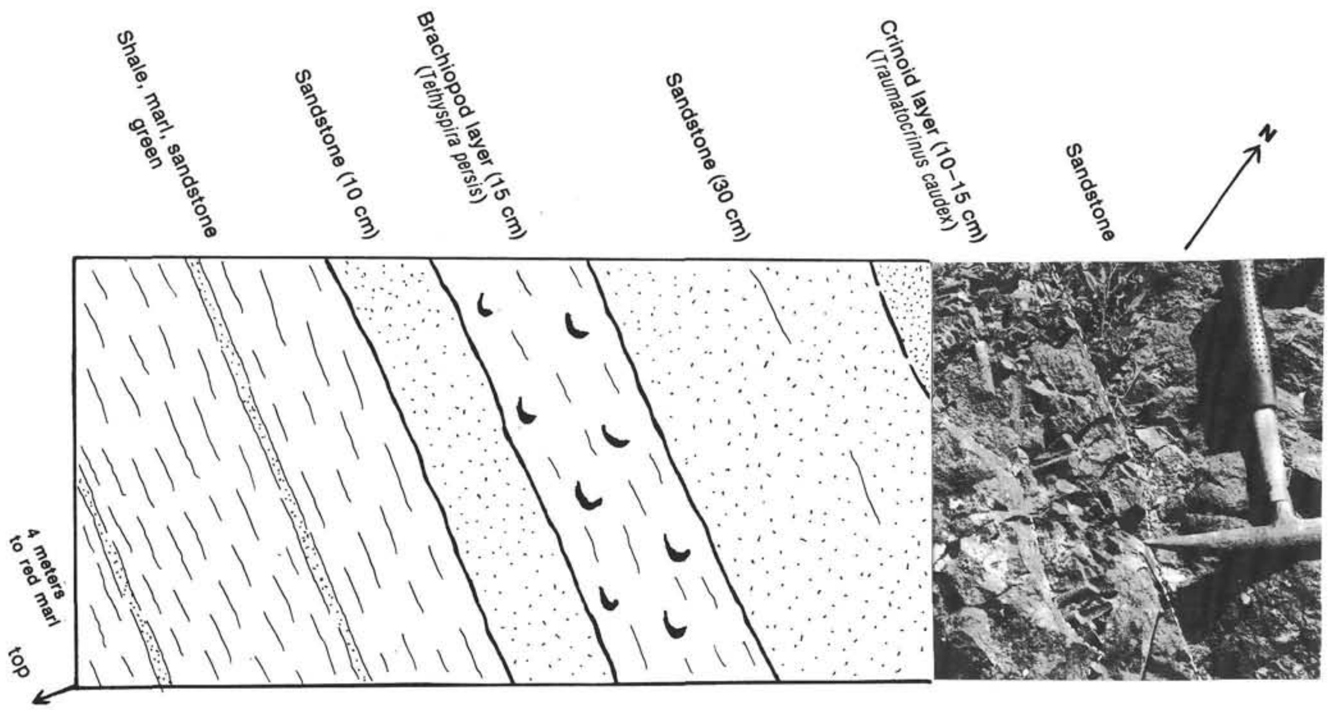


Fig. 19.
Faqir Marl Bed, detailed section.
Fossil locality No. 79, W of Kal-e-Bast.

● Cephalopods
(L. KRYSTYN & F. TATZREITER)

Ammonoids, found by K. T. GOLDSCHMID and the present author in the year 1956, were the first evidence of the Triassic at Aghdarband; previously the coal-bearing beds outcropping in that area were thought to be Jurassic in age. These ammonoids were subsequently studied by R. SIEBER (published in: R. OBERHAUSER, 1960). Although the determinations carried out by SIEBER have had to be revised by L. KRYSTYN & F. TATZREITER, placing the fauna close to the Ladinian–Carnian boundary is not very far from being correct.

The ammonoid fauna is strikingly uniform over the entire mapped area. It is characterized by the dominance of the genus *Romanites* and "the association may therefore be called *Romanites* fauna" (KRYSTYN & TATZREITER, this vol.). According to these two authors this fauna represents the *Frankites regoledosus* zone of the late Upper Ladinian (Longobardian 3); its pan-Tethyan distribution is pointed out by the authors mentioned above.

The samples examined by L. KRYSTYN and F. TATZREITER correspond to the fossil localities, Nos. 35, 36 and 42b (NE of locality No. 35) located west of the Kal-e-Anabeh valley in structural Slice III, to the fossil localites Nos. 30, 32 and 34 located southeast of the Aghdarband village in Slice III, and to fossil localities No. 06 and 20 (the latter being situated south of locality No. 06) located in the Miankuhi region in Slice II. Fossil locality No. 33 (Slice II), at the hill directly west of Aghdarband village, ist the historical location where the first Triassic ammonoids were collected by K.T. GOLDSCHMID (cf. geological sketch map, Fig. 2); the microfacies of a sample (No. AG 10) collected at this site by R. BRANDNER is described in chapter 10 (Addendum).

In these samples

Romanites simionescui KITTL. 1908

occur at nearly all the localities cited above; in addition

Lobites ellipticus (HAUER 1860)

and

Orestites ? sp.

occur rather frequently. The new species

Sphingites n. sp.

was found together with crinoids and brachiopods at Miankuhi, fossil locality No. 20 (SW of fossil locality No. 06, SE of locality No. 22).

Apart from the ammonoids, small orthoceratites are abundant. There are also present large coiled nautiloids, occurring in distinct layers in the Faqir Marl Bed (Fig. 20).

● Brachiopods
(M. SIBLÍK)

In nearly every outcrop of the Faqir Marl Bed specimens of the newly established genus and species

Tethyspira n. gen. *persis* n. sp.

are present in large numbers. As in the case of *Romanites simionescui*, this brachiopod appears to be a guide fossil for the Faqir Marl Bed.

● Echinoderms
(E. KRISTAN-TOLLMANN)

Crinoidea: The third fossil characteristic of the Faqir Marl Bed is

Traumatocrinus caudex (DITTMAR).

Stems of that species occur in abundance in distinct layers of the Bed (Fig. 21).

In addition, columns of

Holocrinus ? *quinqueradiatus* (BATHER)
Balanocrinus sp.
Entrochus sp.

and the pelagic crinoids

Osteocrinus saklibelensis KRISTAN-TOLLMANN
Osteocrinus aghdarbandensis n. sp.
Osteocrinus rectus?
Osteocrinus sp.

have been identified in samples collected from the Faqir Marl Bed.

Holothuroidea: Five species were found in the same samples:

Eocaudina guembeli FRIZZELL & EXLINE
Eocaudina cassianensis FRIZZELL & EXLINE
Achistrum triassicum FRIZZELL & EXLINE
Acanthotheelia spinosa FRIZZELL & EXLINE
Kaliobullites umbo KRISTAN-TOLLMANN

Fig. 20.
Nautiloid, Faqir Marl Bed: Kal-e-Faqir valley.

Fig. 21.
Faqir Marl Bed: layer consisting of stems of *Traumatocrinus caudex*.
Kal-e-Bast, west of fossil locality No. 63.

● **Pelecipods**

In some of the fossil localities of the Faqir Marl Bed (e. g. locality No. 79 to the west, locality No. 30 and the Sina cross-section to the east), shell fragments of

Daonella sp.

were found. Unfortunately these fragments were indeterminable. However, *Daonella lommeli* was identified by L. KRYSTYN in the tuffaceous sandstone, just below the Faqir Marl Bed (fossil localities Nos. 5, 22b and 56) as well as in the tuffaceous shales above the bed (fossil locality No. 27).

● **Foraminifers**
(R. OBERHAUSER)

In 1960, R. OBERHAUSER described a rather rich assemblage of foraminifers removed out of a calyx of *Traumatocrinus caudex* collected in the Faqir Marl Bed in 1956. Marl samples collected in 1975 and 1976 yielded assemblages of forams which are poorer – both in quantity of species and in quality of preservation – than those obtained from a crinoidal calyx. Altogether, R. OBERHAUSER lists the following species:

- Ammodiscidae
  Ammodiscus cf. *infimus* (STRICKLAND)
  Ammovertella persica OBERHAUSER
- Spirillinidae
  Permodiscus ex gr. *eomesozoicus* OBERHAUSER
  Spirillinidae div. sp. (very flat)
- Nodosinellidae
  Lunucammina aghdarbandi (OBERHAUSER)
- Nodosariidae
  Lenticulina münsteri (ROEMER)
  Lenticulina polygonata FRANKE
  Lenticulina aff. *varians* (BORNEMANN)
  Darbyella kollmanni OBERHAUSER
  Marginulina aff. *vetusta* (ORB.)
  Dentalina ex gr. *subsiliqua*
  Dentalina div. sp. (plain)
  Lingulina iranica OBERHAUSER
  Lingulina iranica sieberi OBERHAUSER
  Lingulina aff. *major* (BORNEMANN)
  Lingulina aff. *klebelsbergi* OBERHAUSER
  Frondicularia ruttneri OBERHAUSER
  Frondicularia ex gr. *tenera* BORNEMANN
- Rotaliidae
  Duostomina ex gr. *rotundata* KRISTAN (very flat)

● **Ostracods**
(E. KRISTAN-TOLLMANN)

The shales and marls of the Faqir Bed also provided a small assemblage of ostracods, mostly larvae:

Bairdia sp. sp.
Acratia sp.
Bairdiacypris sp.
Bythocypris sp.
Fabalicypris sp.
Ptychobairdia ruttneri n. sp.
Judahella (Costahella) hungarica KOZUR, 1971
Hungarella sp.
Aneisohealdia aff. *labiata* KRISTAN-TOLLMANN, 1971
Triadohealdia n. sp.
Polycope aghdarbandensis n. sp.

Similar to the underlying tuffaceous Sandstone Member and the sandstone intercalations in the Shale Member, indeterminable plant remnants are also frequently found in the Faqir Marl Bed.

The Shale Member in general

The bulk of the Shale Member consists of tuffaceous shales, dark greenish-grey in colour (No. 10 on the geol. map; Fig. 22); on weathering these shales become brownish in colour and decay frequently to pencil-like bodies ("pencil shales", Fig. 23). They are prinicipally the same in both Slice II and Slice III, but the complete sequence is only exposed to the west of the mapped area in Slice II (cf. Fig. 14).

There – in the flexure of the broad Aghdarband Syncline – an intercalation of thinly bedded tuffaceous sandstone (No. 12 on the geological map) displays well preserved flow casts (Fig. 24), ripplemarks and plant remains on bedding planes. Specimens of plant remains collected in this tuffaceous sandstone proved to be insufficiently well preserved to enable a definite identification (e.g. samples Nos. 76/58, 76/65 and 76/88; M. BOERSMA et al., this vol.). The sandstone is

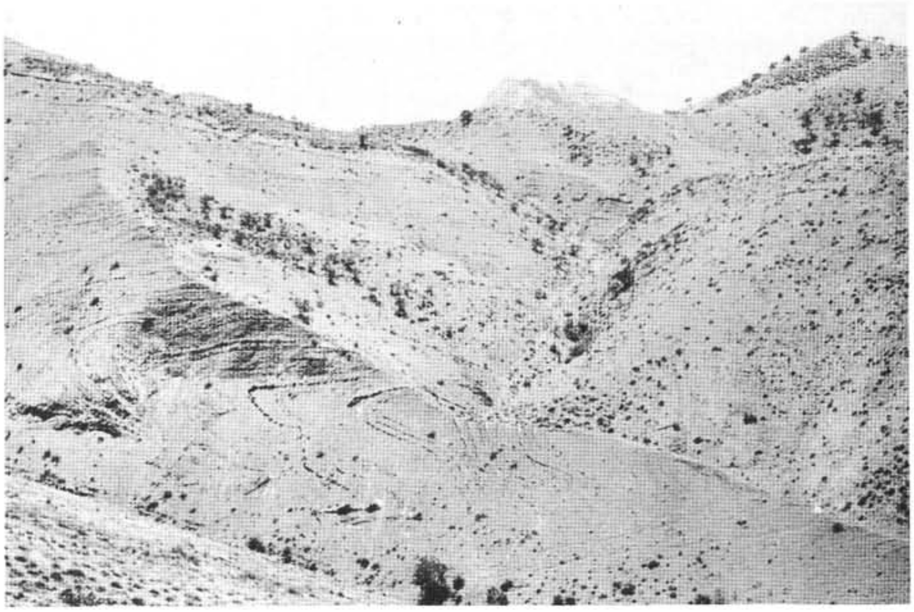


Fig. 22.
Shale Member of the Sina Formation, folded.
South of Tunnel Sina, Structural Slice III.

Fig. 23.
"Pencil Shales", Shale Member of the Sina Formation.
Miankuhi, north of Tunnel 2, structural Slice II.

Fig. 24.
Sandstone showing flow marks.
Shale Member of the Sina Formation, Kal-e-Bast (Kal-e-Faqir).

strongly folded (Fig. 25) and thins out towards the east on the NE-flank of the syncline. A sample of this sandstone (No. 76/65) is described by A. BAUD et al. as a "well sorted tuffaceous subarenite" containing lithic fragments of "quartzofelspathic and quartzo-phyllitic rocks and volcanic glass", as well as "rounded quartz grains, K-felspars, albite, muscovite, biotite, rarely tourmaline and calcite". In comparison with samples of the Sandstone Member, "an increase of metamorphic and plutonic grains from crystalline basement sources" is reported.

Six layers of a more compact dark green-coloured tuffaceous sandstone are shown on the geological map in the southeast plunging anticline west of Aghdarband

Fig. 25.
Folded Sandstone.
Intercalation in the Shale Member of the Sina Formation; Kal-e-Bast, Diagram No. 8.

village (P. 1042). They are interbedded in the shales and pinch out at both sides of the anticline.

A conspicuous layer of compact litharenite (No. 11 on the geological map) marks the top of the Shale Member (Fig. 26). It is similar to the litharenite resting on top of the Sandstone Member; its thickness varies between 5 and 50 meters. The very top of the Shale Member – and consequently the top of the volcanic Sina Formation – is marked by a few meters of bedded tuffaceous sandstone, separating the litharenite from the Coal Bed at the base of the Miankuhi Formation.

This litharenite, resting on top of the Shale Member, displays some peculiarities in the flexure of the Aghdarband Syncline east of Kal-e-Faqir valley

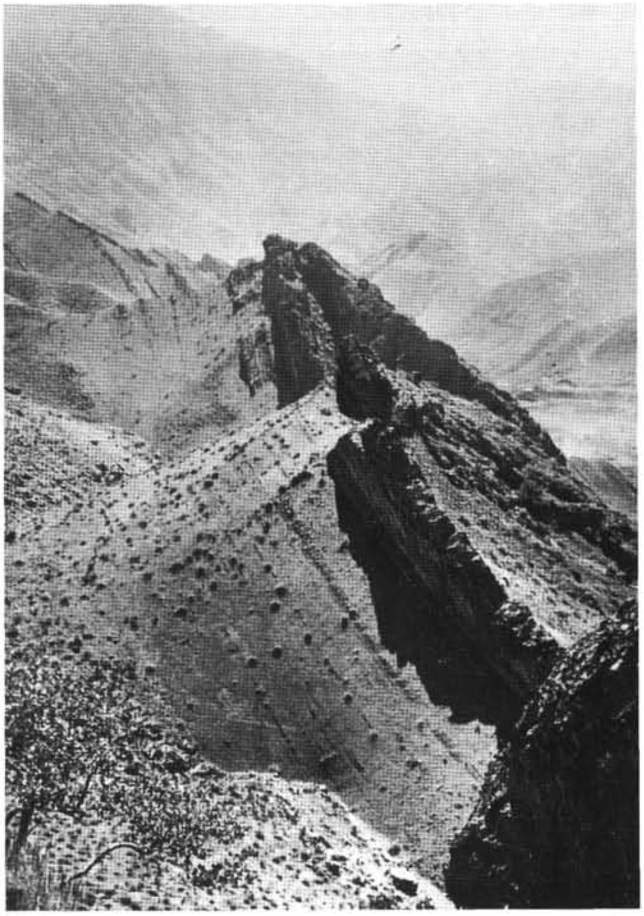


Fig. 26.
Top litharenite of the Shale Member (Sina Formation).
Miankuhi, north of Tunnel 3, P. 1063.

(P. 1162–P. 1184). At the base and on top of this bed, spherical bodies occur up to 40 cm in diameter and are accompanied by volcanic breccia. They show align-

Fig. 27.
?Pillows in the top-litharenite of the Shale Member (Sina Formation).
Kal-e-Bast area, south of P. 1143.

ment parallel with the base – and top respectively – of the litharenite bed and, at the time they were mapped, were thought to be pillows in a type of "tuff-lava" (Fig. 27). A small spheroid (5 cm in diameter), containing fossil fragments and collected below the litharenite bed north of P. 1184, was found to be

" ... *calcareous volcanic microbreccia, containing quartz, K-felspars, albite and trachitic to rhyolitic fragments in a calcitic matrix* ... " (A. BAUD et al., this vol., chapter 4.2.; sample No. 76/67).

Unfortunately, no samples were taken from the large spherical bodies. In my opinion, therefore, the possibility remains that there are lavaflows with pillows hidden in this litharenite bed.

a)

A second peculiar feature of this top-litharenite of the Shale Member, in the central part of the Aghdarband Syncline, is a layer of conglomerate on top of this bed. This conglomerate is restricted to the northern flank of the Aghdarband Syncline, extending there over a distance of only one kilometer and pinching out at both ends (No. 13 on the geological map, in the area of the Kal-e-Bast valley west of Miankuhi). The layers of conglomerate are 2–3 meters thick (Fig. 28a); they are accompanied by a coarse weakly cemented sandstone, showing distinct cross-bedding (Fig. 28b).

The well-rounded pebbles of this conglomerate are generally fist-sized, but may sometimes range to head-size. The major fraction of the pebbles consists of a dense, light green-coloured rock, which according to A. BAUD et al. (this vol., chapter 4.2.; sample No. 76/66) is an ignimbrite of dacitic composition. Along with these, other reworked volcanic rocks predominate. In addition, small white quartz (or quartzite) pebbles frequently occur. Some pebbles, consisting of a light green limestone, were noted to be similar to a limestone outcropping in the Paleozoic sequence of the Northern Frame.

Calcareous intercalations in the shales of the Shale Member contain small crinoids, pelecipods and brachiopods. These fossiliferous beds occur particularly frequently immediately below the top-litharenite referred to above. Sample No. 75/27, collected in the shale close to the top-litharenite in the anticline west of Aghdarband village (SSE P. 1042) contains, among others, shells of

Daonella lommeli (WISSMANN 1841)
Protrachyceras ? sp. ind.

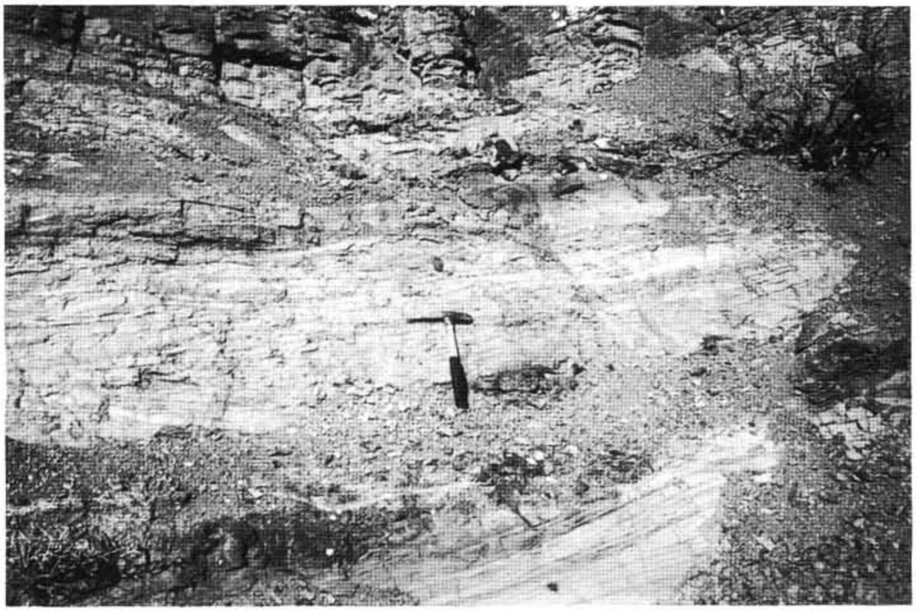
according to L. KRYSTYN & F. TATZREITER (this vol.). Another sample collected close to the base of the Member in the Kal-e-Faqir valley (No. 76/58, south of fossil locality No. 57) provided a specimen of

Gervatites ? sp. ind.

These findings suggest that most of the Shale Member is Latest Ladinian (Longobardian 3) in age.

The top of the Member, however, is Early Carnian.

Fig. 28.
Top of the Shale Member of the Sina Formation (No. 13 on the geological map, Plate 1).
a) Conglomerate.
b) Cross-bedded Sandstone.



b)

This is proved by a sample of siliceous limestone collected of a layer which crops out, about 80 centimeters thick, between tuffaceous sandstone immediately below the Aghdarband Coal Bed at a ridge ESE of the Aghdarband village, i. e. about 400 meters ESE of the "Gesenke" (winze) of the coal mine.

A rich assemblage of radiolarians and spicules of porifers found by D. DONOFRIO (this vol.) in that sample (No. Agh76/61) points to a Late Cordevolian age of this limestone.

● **Radiolaria**

In this assemblage the two new species

Spicularina n. gen. *ericae* n. sp and
Vinassospongus ruttneri n. sp.

are more predominant than

Sarla vetusta PESSAGGIO, 1979
Plafkerium contortum DUMITRICA, KOZUR & MOSTLER, 1980
Poulpus aff. *P. phasmatodes* DE WEVER, 1979
Spongopallium contortum DUMITRICA, KOZUR & MOSTLER, 1980
Poulpus sp. DE WEVER, 1979
Mosotylus sp. CAYEUX, 1897
Capuchnosphaera sp. DE WEVER, 1982

● **Porifera (Spicula)**

Of the Megascleres

" *... nearly all main types are present: Monaxons, Triaxons and Tetraxons; only the Desmas are missing ...* " (D. DONOFRIO, this vol.)

Of the Microscleres

" *... only two polyctine spicules were found. Based on morphological comparisons of the microscleres Calvule and Scopule as well as of the megasclere Pinulhexactine with scleres of the same morphologic categories from older and/or younger occurrences, the association of porifers in question can be timed and assigned – like the Radiolarians – to the early Late Triassic (Late Cordevolian) ...* " (D. DONOFRIO, this vol.).

Another sample (No. AG11) collected by R. BRANDNER just to the west of the Aghdarband village yielded radiolarians (*Poulpus piabyx* DE WEVER, det. DONOFRIO) which point also to a Cordevolian age of the uppermost parts of the Sina Formation (cf. Addendum, chapter 10.).

Since the Coal Bed of the overlying Miankuhi Formation is presumably Norian–Rhaetian in age (cf. BOERSMA et al., this vol.), a gap in sedimentation between the Sina and Miankuhi Formations exists, comprising essential parts of the Carnian and Norian stages.

The shales of the Shale Member also yielded the crinoid

Isocrinus aff. *rollieri* (LORIOL, 1886)

hitherto found only in Upper Liassic beds (see KRISTAN-TOLLMANN, this vol.). This sample (No. 75/33a) was collected just SW of the Aghdarband village in tuffaceous shales, immediately below the basal Coal Bed of the Miankuhi Formation. Since the shales of that location are Latest Ladinian or Earliest Carnian in age, a Liassic age of these shales is not feasible.

*

Discriminating the Shale Member from Sandstone Member in structural Slice II is not as evident in the region east of the Aghdarband village as it is in the western part of the area. The easternmost outcrop of the separating Faqir Marl Bed in Slice II is the historical locality No. 33, just west of the village. East of the village – and south of the fault that separates Slice I and Slice II – are exposed predominantly tuffaceous shales; an interbedded layer of whitish to light green coloured sandstone (+ quartz conglomerate; No. 13 on the geological map) divides these shales into a northern – more sandy – and a southern – purely shaly – part. At one location (fossil locality No. 60, SE of Aghdarband village) the brachiopod

Tethyspira n. gen. *persis* n. sp.

was found in this intervening bed (see SIBLÍK, this vol.). It is conjectured therefore that this sandstone layer is possibly an equivalent of the Faqir Marl Bed. If this is so, the shales interbedded by sandstone north of the whitish sandstone-layer correspond with the Sandstone Member, the shales south of it, on the other hand, with the Shale Member. The latter is immediately overlain by the Coal Bed of the Miankuhi Formation; the top litharenite of the Shale Member is missing there.

Farther east, the tuffaceous shales are intensively folded, along with the Coal Bed and the shales of the Miankuhi Formation. Also doubled by folding is the whitish sandstone layer. All the same, the Shale Member of the Sina Formation thins out towards the east: the Coal Bed of the Miankuhi Formation is enfolded in a tuffaceous sandstone of the Sandstone Member of the Sina Formation with only a thin separting shale between them.

In Slice III the separation between the two Members of the Sina Formation is as well established as in the western part of Slice II both lithologically and by the presence of a typically developed Faqir Marl Bed (fossil localites Nos. 02, 36, 35; Sina cross-section, strat. sections 1 and 2). The same is the case in the western part of Slice III (fossil localites No. 34, 32, 30).

In the Sina cross-section, the "pencil shale unit", part of the Shale Member,

" *... consists of thinly bedded calcareous shale, with occasionally plant remains and crinoidal stems, and of marly limestone interbedded with volcanic arenite and rudite, and tuffaceous skeletal lime wackestone to packstone, with thin ornate shells of Halobia-like bivalve ...* "

" *... This shaly unit has suffered an intense isoclinal folding and pencil-like superficial alteration ...* " (A. BAUD et al., this vol., chapter 3.2.4.).

The tuffaceous sandstone and layers of litharenite SE of the Aghdarband village is probably the folded top-litharenite of the Shale Member, though at fossil locality 29 *Traumatocrinus caudex*, not previously found at the top of the Member, is present.

3.2.4. Miankuhi Shale Formation

Nos. 9, 8, 7 on the geological map
Formerly "Non-Marine Shale Member (4)"

The core of the Aghdarband Syncline consists of a rather monotonous sequence of brown-coloured shales, with some interbedded siltstone and/or fine-grained sandstone. The Syncline is well developed in the Miankuhi region west of the Aghdarband village; hence the name. "Miankuhi" means "Between the Hills" being, thus, an appropriate name for that Formation.

The base of the Formation is the Aghdarband Coal Bed, which was – and still is – the main reason for the mining activities in the Aghdarband region. This Coal

Bed contains a florule, probably Norian in age (M. BOERSMA & J.H.A. VAN KONIJNENBURG-VAN CITTERT, this vol.). The overlying monotonous shales yielded merely a persistent benthonic microfauna (R. OBERHAUSER and S. PREY, see below).

The Aghdarband Coal Bed

(Nos. 9, 8 on the geological map)

The Coal Bed (formerly named "Coal Horizon") is well exposed at the northern flank of the Aghdarband Syncline at Miankuhi, west of Aghdarband village. The composition of the Bed is shown by a cross-section measured above the mouth of "Tunnel 3", E of Kal-e-Jom'eh valley (Fig. 29).

The coal seam is generally about 1 meter thick. It is underlain by a root clay, consisting either of coaly shales or of a bleached and decomposed tuffaceous sandstone (Fig. 30). Plant-bearing dark grey shales compose the hanging wall of the seam, grading upwards into a brown-weathering thick-bedded non tuffaceous sandstone the latter being generally up to 5 meters thick.

This "hanging sandstone" also contains plant remains and in its turn grades upwards into the shales through alternate layers of sandstone and shale.

In the region east of Aghdarband village ("Gesenke" – "Nuhi [W]" – "Nuhi [E]" – "Sina") the composition of the Coal Bed is the same as at Miankuhi, but cannot be as readily studied there because of intensive folding.

The bituminous coal contains up to 20 % ash; it is a coking coal amenalbe to coke conversion in simple coke furnaces (Fig. 31).

The coal seam marks the beginning of a new phase of sedimentation, and the tuffaceous sandstone below the seam indicates the end of volcanic activity. The "hanging sandstone" above the coal seam is characterized by the dominance of quartz grains, the presence of mica and its brown coloration. Sample No. 75/19, collected in this "hanging sandstone" west of Miankuhi close to the Kal-e-Bast valley,

> " ... *is a fine grained, well sorted litharenite containing abundant plant remains, quartz, felspar, muscovite, biotite, secondary calcite and lithic fragments of phyllitic rocks ...* " (A. BAUD et al., this vol., chapter 4.3.).

There are also layers of intercalated reworked volcanic material in this "hanging sandstone". A sample collected at the dump of tunnel "Sina" (76/94) is a

> " ... *coarse-grained volcanic litharenite with well-rounded volcanic fragments ...* "

and is very probably derived from such an intercalation; it

> " ... *contains devitrified glass, volcanic quartz and felspars, detrital phyllitic minerals (illite, muscovite) and opaque minerals ...* "

A conglomerate, consisting of volcanic material as an intercalation of the „hanging sandstone" is recorded

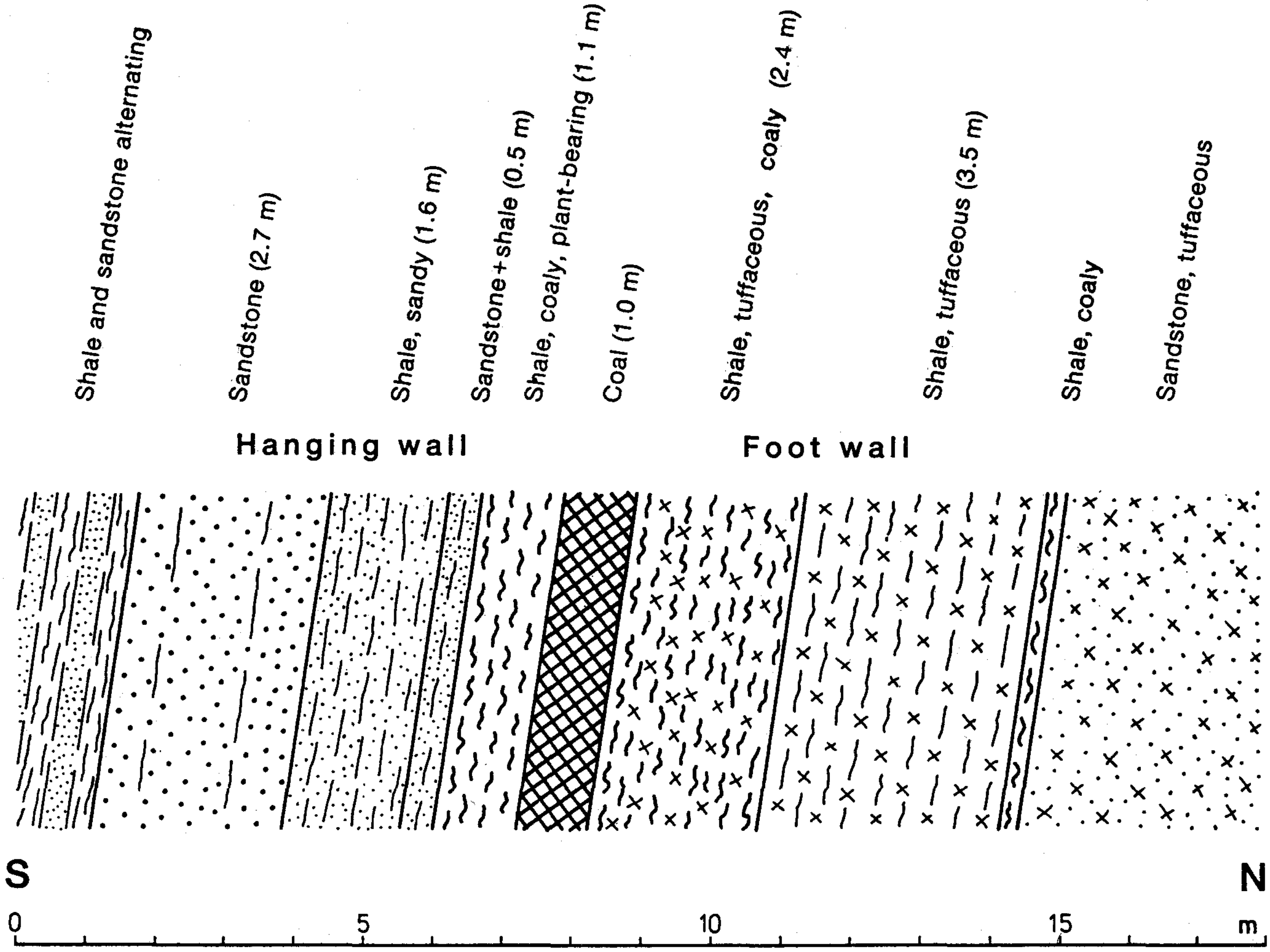


Fig. 29.
The Aghdarband Coal Bed, detailed section.
Measured above the mouth of Tunnel 3, Miankuhi, east of Kal-e-Jom'eh.

Fig. 30.
The Aghdarband Coal Bed; above the mouth of Tunnel 3, Miankuhi, east of Kal-e-Jom'eh.
1 = hanging sandstone; 2 = hanging plant bearing shales; 3 = coal seam (disturbed); 4 = footwall (decomposed tuffaceous sandstone).

from Tunnel "Nuhi". But, apart from these reworked volcanic interbeddings, the "hanging sandstone" is free of volcanic influence.

The new phase of sedimentation was not only non-volcanic, but also was very probably separated from the top of the Sina Formation by a considerable stratigraphic gap (cf. previous chapter and Tab. 1).

Plant remains were the only age-indicative fossils found so far in the shales and sandstones in and above the Coal Bed.

These abound in the shales between the coal seam and the "hanging sandstone", and – in contrast to the plant remnants in the underlying volcanic turbidite sandstones – they are reasonably well preserved. Palynomorphs are also present in the shales, but

" ... palynological data remained inconclusive because of the strong carbonization of organic material. Part of the plant megafossils, on the other hand, are well enough preserved to be identified" (M. BOERSMA & J.H.A. VAN KONIJNENBURG-VAN CITTERT, this vol.).

These plant megafossils were colleted in the western part of the area (Miankuhi) as well as in the eastern part (Tunnel "Sina").

The following taxa are described and discussed by the authors mentioned above:

Miankuhi west
Fossil localities No. 19 and No. 95 (300 meters east of locality No. 19)

- Equisetophyta
  Neocalamites sp. A
- "Pteridophylla" sensu NATHORST
  Taeniopteris sp. A.
- Coniferae
  Podozamites paucinervis nov. sp.
  Podozamites sp.
- Incertae sedis
  Carpolithes cf. *cinctus* NATHORST
  Seed scale

Tunnel "Sina"
Fossil locality No. 94

- "Pteridophylla" sensu NATHORST
  Taeniopteris sp. A
- Ginkophyta
  Sphenobaiera sp. A
- Coniferae
  Podozamites sp.

Fig. 31.
Coking plant, Aghdarband Coal Mine.

The florule is characterized by the dominance of the genus *Podozamites* and by the presence of a Norian type of the genus *Sphenobaiera*; this shows a general resemblance with the Norian flora of the Amba river, U.S.S.R.

" ... So a Norian age seems more probable than a Karnian or Rhaetian one ... " (M. BOERSMA et al., this vol.)

At fossil locality No. 64, in the southern Kal-e-Bast valley, a tree stump was found standing perpendicular to the bedding planes of coaly shales (Fig. 32); this find and the root-clay below the coal seam suggest that the coal seam is autochthonous. A considerable gap of time has to be assumed as having existed between the (probably Norian) coal bed and the latest Ladinian (or early Carnian) tuffaceous sandstone below. Layers of conglomerate and of cross-bedded coarse sandstone underneath the Coal Bed south of Kal-e-Bast (No. 13 on the geological map) support this inference (see chapter 3.2.2.3.).

Three subsidiary synclines of the Coal Bed could be traced in the broad hinge of the Aghdarband Syncline south of Kal-e-Bast, despite the loess cover there. A fourth subsidiary syncline triples the coal seam on the northern flank of the main syncline west of Miankuhi, west P. 1166 (section 2, Pl. 2).

The Aghdarband Syncline is strongly compressed and subdivided into several secondary folds in the region east of the Aghdarband village; accordingly, the Coal Bed is repetitive and partly severely distorted there (sections 4 and 5, Pl. 2).

Zig-zag folds of the Coal Bed can be seen immediately south-east of Aghdarband village, south of "Gesenke" (see map Pl. 1 and Fig. 46). There, the tuffaceous footwall of the coal seam contains two layers of brownish limestone (sample No. 76/61) in which D.A. DONOFRIO found radiolarians and spicules of porifers indicating a Late Cordevolian age of this limestone (cf. previous chapter).

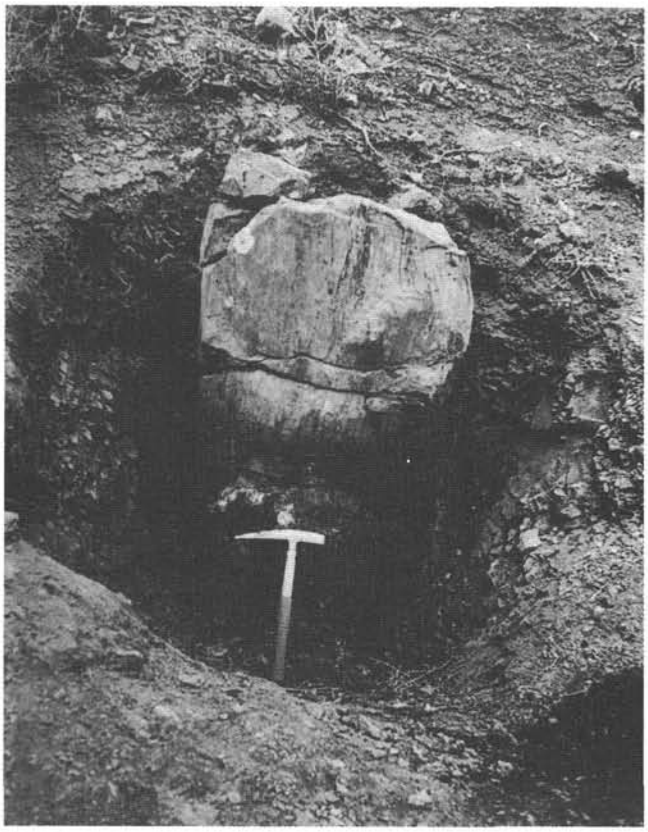


Fig. 32.
Tree-stump in the Aghdarband Coal Bed.
Kal-e-Bast, fossil locality No. 64.

Intensive folding of the Coal Bed was encountered in the mining district of the "Nuhi" and "Sina" Tunnels. The thickness of the coal seam varies there between 4 meters and almost nil, due to strong tectonic deformation. Three to four isoclinal synclines could be identified underground in the mine, as well as at the surface. The axes of these folds are inclined slightly eastward in the western part ("Nuhi" – west), but rise towards the east in the eastern part ("Sina") of that folded section; therefore the Coal Bed and the shales of the Miankuhi Formation crop out towards the east in a narrow folded west plunging syncline east of Tunnel "Sina". There, at the eastern end of the Aghdarband Syncline, the Coal Bed rests on a tuffaceous sandstone of the Sina Formation.

The Coal Bed is also exposed on the front-limb of thrust-Slice III. The coal seam was found to be badly distorted in the "Allahverdi" Tunnel because of its position close to the thrust fault.

The Miankuhi Shales

The shales (No. 7 on the geological map; cf. also panorama, Fig. 3) of the Miankuhi Formation are strikingly uniform. They differ clearly from the greenish coloured tuffaceous shales of the Sina Formation, Shale Member, by their brownish colour.

Originally, these shales were thought to be of nonmarine origin, because of their seeming barrennes of fossils (cf. A. W. RUTTNER, 1983, 1984, 1988, and the geological map Pl. 1). Lately, however, R. OBERHAUSER and S. PREY found a poor assemblage of agglutinated tests in a sample newly (1988) collected by J. EFTEKHARNEZHAD & A. BEHROOZI by request of the present writer, consisting of:

Ammodiscus sp. (small-sized)
Reophax sp.
Nodellum sp.
Saccaminidae (pinched)
Trochamminidae
Textulariidae
Dendrophyrae (fragments)
Hypersurmina sp.
Ammo sculites sp.
cf. *Eudothyra* sp.
cf. *Heterohelix* sp.

According to R. OBERHAUSER and S. PREY, this marine benthonic microfauna points to an extremely adverse living environment.

Fine sandy interbeds, each 1–2 centimeters thick, were observed in a rhythmic succession at intervals of 30 to 40 centimeters about 350 meters southeast of "Tunnel 3" (P. 965) in the Miankuhi region. A layer of fine-grained sandstone five meters in thickness, well bedded and alternating with shales, was found 180 meters south of "Tunnel 4".

The shales are about 200 meters thick in the core of the Aghdarband Syncline.

3.3. The Ghal'eh Qabri Shale Beds

Some prospecting for coal was also carried out west and north of the village Ghal'eh Qabri; it brought to light a minor coal seam and plant megafossils. A number of specimens of the latter were collected on the occasion of a short visit at that site in the spring of 1975, before starting the mapping campaign in the Aghdarband area. Ghal'eh Qabri is a small village about 11 kilometers to the east-south-east of the Aghdarband village, that is about 4 kilometers east of the south-eastern limits of the mapped area (cf. Fig. 1).

One or two thin coal seams and the plant remains are imbedded in a white quartz-sandstone; this sandstone is 10–20 meters thick and lies unconformably and horizontally on the Sefid Kuh Limestone, which is in turn folded into a tight anticline. As in the Anabeh valley in the eastern Aghdarband area, this limestone forms part of the front limb of thrust Slice III; at Ghal'eh Qabri it carries the ruins of an old fortification. The white sandstone is overlain by black shales; most of the surroundings of the village consist of brown-weathering shales.

The plant megafossils, collected close to the castle-ruin mentioned above (sample No. 75/03) are described and discussed by M. BOERSMA & J. H. A. VAN KONIJNENBURG-VAN CITTERT in this volume. The following taxa are quoted by these authors:

- Pteridophyta
  Cladophlebis sp. A
- Cycadophyta
  Pterophyllum cf. *ptilum* HARRIS
  Pterophyllum cf. subaequale HARTZ
- "Pteridophyta" sensu NATHORST
  Taeniopteris sp. B
- Coniferae
  Pagiophyllum ruttneri nov. sp.
  Stachyotaxus elegans NATHORST.

This florule is different from that of the Aghdarband Coal Bed at the base of the Miankuhi Formation. The two species of the genus *Pterophyllum* occur only in the Rhaetian, and the conifer *Stachyotaxus elegans* has

" ... mainly been recorded from the Rhaetian until now ... "

All three species disappear at the Rhaetian–Liassic boundary; therefore

" ... an assignment to the Jurassic can be excluded ... " (M. BOERSMA et al., this vol.).

A Rhaetian age of this florule seems to be most probable according to these authors.

Air photos and Landsat images reveal that the shales which overlie the plant bearing sandstone obscure all tectonic structures known from the Aghdarband area, with the exception of the southernmost major fault, i. e. the Shahtutak Fault which clearly affects this shale cover (cf. the geological map prepared by J. EFTEKHARNEZHAD & A. BEHROOZI, this vol., and Fig. 1 of the present paper).

Thus, it is not possible to include these shales and their plant-bearing base in the Miankuhi Formation. On the contrary, the black shales of Ghal'eh Qabri and their basal sandstone are in the same geological position as the Jurassic Kashafrud Formation is found elsewhere in this area. The latter rests generally with a basal conglomerate on Hercynian and/or Cimmerian folded older rocks. This basal conglomerate of the Kashafrud Formation is 90 meters thick in the type section of the Formation measured by M. MADANI in the area to the WNW of the Aghdarband, 15 kilometers east of the village of Baghbaghoo on the road to the Aghdarband coal mine (M. MADANI, 1977). The first marine fossils (ammonites of Bajocian age) appear not earlier than 170–200 meters above the base of the Formation.

The Rhaetian plant bearing sandstone and the overlying black shales of Ghal'eh Qabri may correspond to the – apparently – non-marine lowest part of the Kashafrud Formation, as it is shown on the geological map of EFTEKHARNEZHAD & BEHROOZI (Fig. 2 of their contribution) and on the structural sketch map, Fig. 1, of this paper. However, they may also be considered to be a locally developed individual formation. A final decision will be possible only after a detailed mapping is carried out in the area to the east of the village of Ghal'eh Qabri. For the time being they may be named Ghal'eh Qabri Shales.

Nevertheless, both florules – that of Ghal'eh Qabri and that of the Aghdarband Coal Bed – confine the Early Cimmerian Orogeny to the time-span ? Late Norian – Early Rhaetian.

4. The Northern Frame

The Triassic rocks of the Aghdarband Group are bounded to the north-north-west by a major fault, i. e. the Northern Main Fault (see chapter 6, Structure). The pre-Triassic rocks, which are exposed north of this fault, were studied by the present author in two cross-sections only; detailed mapping of that extremely rugged area was not possible because of lack of time.

4.1. The Paleozoic sequence

(Nos. 25, 26, 27, 28, 29 and 30 on the geological map, Plate 1)

The two cross-sections mentioned above show an almost identical sequence of rocks. One of them is that along the road in the gorge just north of the Aghdarband settlement (Fig. 33), the other one is exposed along the lower course of the Kal-e-Anabeh stream 4 kilometers farther to the east. The following sequence of rocks can be observed in both sections from the north to the south:

A thin (cm) bedded limestone (No. 26 on the map; Fig. 34), dark grey to black in colour, outcrops at the southern slope of the Kashaf Rud valley. The limestone is interbedded with black shale, greenish-coloured sandstone and "diabase". This succession of beds is intensely folded and mildly metamorphosed; the general dip is northerly. The same rocks are also exposed along the northern slope of the Kashafrud valley.

In samples of this dark limestone, collected at the mouth of Kal-e-Anabeh (No. 75/41) and at the mouth of

Fig. 33.
The Northern Frame: Paleozoic rocks, unconformity.
Gorge situated to the north of the village of Aghdarband.

the Aghdarband gorge (No. 75/44; Fig. 34.), H.P. SCHÖNLAUB (this vol.) discovered and determined the following conodont taxa:

Ancyrodella sp. aff. *A. nodosa* ULRICH & BASSLER
Palmatolepis triangularis SANNEMANN
Palmatolepis minuta minuta BRANSON & MEHL
Palmatolepis delicatula delicatula BRANSON & MEHL
Polygnathus sp.
Nothognathella sp.

and assignes this fauna to the early Upper Devonian (i. e. of late Frasnian to early Fammenian age). The conodonts of sample No. 75/41 (collected at the mouth of the Kal-e-Anabeh valley) are slightly younger than those of sample No. 75/44 (collected north of the Aghdarband settlement). In addition, samples collected recently by the GSI-team yielded the following microfauna (determined by B. HAMDI in J. EFTEKHARNEZHAD & A. BEHROOZI, this vol.):

- Conodonts:
  Polygnathus sp.
  Polygnathus cf. *xylus* ZIEGLER & KLAPPER
  Polygnathus normalis MILLER & YOUNG equst.
  Roudya sp.
  Prioniodina sp.
  Prioniodina frona (HUDDLE)
  Ozarkodina sp.
  Polygnathellus sp.
  Bryantodus sp.
  Ligonodina sp.
  Camtognathus sp.
  Neoprionodus group
- Forams:
  Lunucammina sp.
  Archaesphaera sp.
  Saccaminopsis sp.
  Endothyra ? sp.

in addition to algae, shell fragments and microgastropoda. According to B. HAMDI, this microfauna also indicates late Frasnian to early Fammenian age of this limestone.

South of this limestone, one passes through a thick sequence of dark green coloured rocks which consists

Fig. 34.
The Northern Frame: Devonian limestone.
Kashaf Rud valley, southern slope, east of the Aghdarband gorge.

Fig. 35.
The Northern Frame: Devonian dark green coloured rock sequence.
View from P. 1293 (NE Kal-e-Bast) towards north (Kashaf Rud).

of sandstone, microbreccia, breccia, conglomerate and slate (No. 27 on the map; Fig. 35). These rocks are extremely hard and slightly metamorphous. Rounded quartz pebbles are frequently embedded in layers of coarse-grained sandstone. Particularly striking are bright orange-red or light green coloured fragments of jasper, ranging up to 5 cm in dimensions.

The groundmass and a part of the coarser fragments of these clastic rocks are of volcanic origin (see chapter 4.2.).

The total thickness of this dark-green rock assemblage is about 700 meters in the Kal-e-Anabeh section. This is, very probably, a secondary thickness, caused by intense internal folding and deformation; the primary thickness may have been less than half of this total. A chip of marble interposed in the southern part of the green rock sequence indicates such strong tectonic deformations. Bedding planes dip steeply towards the north.

The dark green volcaniclastic rock sequence is also well exposed along the road in the gorge north of the Aghdarband settlement, but its thickness is reduced considerably there compared with that of the Kal-e-Anabeh section. West of the gorge, a strip consisting of light green coloured slates, 50 meters wide and 800 meters long, is interbedded in the dark green clastic rock sequence close to its southern border (No. 28 on the map). Interstratified in these slates are layers of light green coloured crystalline limestone, 0.5–1.0 meters thick each. Similar rocks are also exposed along the northern slope of the Kashaf Rud valley, outside of the mapped area. These limestone beds contain badly preserved conodonts, from which H.P. SCHÖNLAUB (this vol.) could identify the following (samples No. 76/67a, west of the Aghdarband gorge, and 76/84, northern slope of the Kashaf Rud valley):

Palmatolepis glabra pectinata ZIEGLER
Palmatolepis glabra prima ZIEGLER & HUDDLE
Palmatolepis gracilis gracilis BRANSON & MEHL
Palmatolepis glabra cf. *distorta* BRANSON & MEHL
Palmatolepis marginifera marginifera HELMS
Tripodellan element.

This fauna is somewhat younger (Lower Fammenian) than that of the black limestone (cf. H.P. SCHÖNLAUB, this vol.).

The southernmost member of the pre-Triassic rock sequence of the Northern Frame is a recrystallized limestone, bluish-grey in colour ("marble", No. 29 on the map, Pl. 1); it follows the Northern Main Fault to its full length (7.5 km) in the mapped area, though varying considerably in thickness. It is crossed by the Kal-e-Anabeh stream and that of Aghdarband in narrow gorges.

The recrystallized limestone is about 200 meters thick in Kal-e-Anabeh gorge. At the northern end of the winding gorge, a conglomerate, or a conglomeratic breccia respectively, adjoins this "marble", alternating with green sandstone and slate, containing – among fragments of green and violet coloured slates – rounded pebbles of crystalline limestone. This conglomeratic breccia forms the transition to the dark green volcaniclastic rock sequence described above. South of the limestone, the Northern Main Fault is a vertical (to somewhat northerly inclined) tectonically mixed zone (mylonite), at least 20–30 meters wide which consists of green sandstone of the Sina Formation alternating with bluish-grey "marble".

At the gorge leading from the Aghdarband settlement northward down to the Kashaf Rud valley (cf. Fig. 33), the Northern Main Fault – and the mylonite zone associated with it – is inclined very steeply towards the north (Fig. 36). Many "diabase" dykes cut the marble as well (Fig. 37) as the boundary between the marble and the dark green clastic rock sequence. The conglomeratic breccia at that boundary – exposed in a steep ravine at the west side of the gorge – contains pebbles of white quartz, red and green jasper, green volcanic rock, siliceous slate, and recrystallized limestone.

Originally, the present writer took this "marble" for the oldest (pre-Late Devonian) member of the pre-Triassic rock sequence exposed in the Northern Frame (cf. A. RUTTNER, 1983, 1984); the pebbles of "marble" in the transitional conglomeratic breccia between the "marble" and the dark green clastic rocks were believed to be a proof of a pre-Hercynian (Caledonian, or even pre-Cambrian) orogeny.

New findings made by the GSI team disprove this assumption. The limestone pebbles in the conglomeratic breccia mentioned above contain a microfauna pointing to a late Devonian to early Carboniferous age of the limestone from which the pebbles are derived (B. HAMDI in EFTEKHARNEZHAD & BEHROOZI, this vol.):

Lonchoclina sp.
Hindeodella spp.

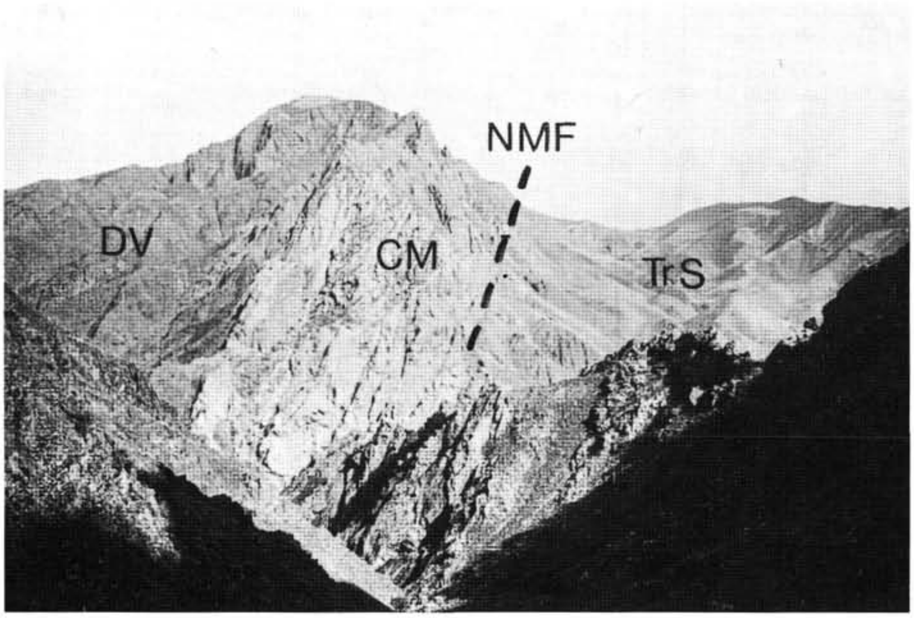


Fig. 36.
The Northern Frame: Upper Devonian dark green coloured volcaniclastic rock sequence (DV) and Lower Carboniferous Limestone ("marble", CM), dipping steeply towards the north.
Eastern side of the Aghdarband gorge.
NMF = Northern Main Fault; TRS = Triassic Sina Formation.

Polygnathus sp.
Polygnathus cf. *webbi* STAUFFER
Neoprioniodus sp.
Prioniocllna sp.
Ligonodina sp.
fish tooth
crinoid stem segments.

Fig. 37.
The Northern Frame: "Diabas" dyke in Lower Carboniferous limestone ("marble").
NNE of the village of Aghdarband.

Hence, this conglomeratic breccia is probably earliest Tournaisian in age, and a comparison with the post-Caledonian Gedinne conglomerate of the "Rheinische Masse" (West Germany) is not possible any more (cf. K. WEDDIGE, 1984a, 1984).

Moreover, in layers of grey recrystallized biomicritic limestone in the "marble" close to its northern boundary, B. HAMDI found:

Parathurammina sp.
cf. *Saccaminopsis* sp.
Earlandia sp.
Archaesphaera sp.
Archaesphaera cf. *minima*
Diplosphaerina sp.
Lunucammina sp.
Microgastropoda

which point to an early Carboniferous (Tournaisian) age. HAMDI considers these biomicritic beds to be transition beds from Upper Devonian to Lower Carboniferous. Even samples taken from upper massive parts of the "marble" yielded the following foraminifera:

Paleotextularia sp.
Tolypammina sp.
Trochammina sp.
Lituotuba sp.
Archaesphaera sp.

in addition to rugose corals, crinoid stem fragments, microgastropoda, ostracods, echinoid spines, echinoderm stem fragments, fishteeth, fish scale, fishplate, and Holothurian sclerite. EFTEKHARNEZHAD & BEHROOZI (this vol.) compare this recrystallized limestone with the Mobarak Limestone, and the Members B, C and D of the Geirud Formation respectively of the Alborz Mountains.

Thus, there exists an uninterrupted stratigraphic succession from Upper Devonian to Lower Carboniferous in the area between the Kashaf Rud valley and the Northern Main Fault. Contrary to the writer's original assumption, this sequence of beds becomes gradually younger from north to south. The grade of metamorphism appears to increase in the same direction, corresponding to the state of preservation of the conodonts (cf. H.P. SCHÖNLAUB, this vol.): the conodonts obtained from the light green coloured recrystallized limestone layers in the slates which are exposed to the south, i e. west of the Aghdarband gorge (sample locality No. 76a) are considerably more altered than those obtained from the black limestone at the southern slope of the Kashaf Rud valley (sample localities Nos. 44 and 41) to the north. However, it should be noted that the conodonts of sample No. 84 which was collected still farther north (from the northern slope of the Kashaf Rud valley) show the same high graded alteration as the conodonts of sample No. 76a in the extreme south. For some reason, the younger (Fammenian) assemblage of conodonts appear generally to be more altered than the older (Frasnian) one.

On the whole,

" *... the small conodont fauna is assigned to an offshore environment at the continental margin ...* " (H.P. SCHÖNLAUB, this vol.).

Black limestones and light-green and violet slates also occur north of the Kashaf Rud valley. Slates, reddish-brown in colour (No.25 on the map), outcrop in the lower part of the Kal-e-Faqir valley, north-west of the mapped area; they show indistinct fossil traces. Thus, the stratigraphic range of the rock sequence existing in the Northern Frame is far from fully known. Nevertheless, the proof of a Late Devonian to Early Carboniferous stratigraphic sequence, which shows an oceanic – though marginal oceanic – character, is of importance to future paleogeographic reconstructions.

4.2. Late Devonian Volcanism

Green coloured volcanic rocks – provisionally named "diabase" – were found occurring in three ways in the two cross-sections described above:

1) As dykes intersecting both, the dark green Upper Devonian clastic rock sequence and the Lower Carboniferous limestone ("marble").
2) As part of the ground mass of the dark green Upper Devonian clastic rock sequence.
3) Interbedded with the thin-bedded dark grey Upper Devonian limestone.

A detailed study of these volcanic rocks is beyond the scope of this paper. Yet, E. KIRCHNER (University Salzburg) kindly examined 5 thin sections made from samples partly newly collected by J. EFTEKHARNEZHAD & A. BEHROOZI. E. KIRCHNER's diagnostic descriptions shed an interesting new light on these rocks.

Sample 88/08 is a dark green coloured "diabase" collected by J. EFTEKHARNEZHAD & A. BEHROOZI in the gorge situated to the north of the Aghdarband village, probably from a dyke. Two slides were made. E. KIRCHNER notes:

○ Slide No. 2

"An intersertal texture of felspar laths, the interstices being filled by chlorite. Heavily altered pyroxene, abundant quartz in the shape of euhedral or subhedral crystals. Carbonate as individual crystals or also along the grain boundaries. Segregation of limonite around the chlorite crystals.
Estimated proportion of minerals:
Plagioclase (50 %)
Quartz (20 %)
Pyroxene (20 %)
Ore
The rock in question may be a d a c i t e *or an* a n d e s i t e."

○ Slide No. 3

"A fine-grained effusive rock, the same as slide No. 2, containing plagioclase laths which are intergrown with mica. Chlorite fills the interstices. Pyroxenes are colourless, fissured, and mostly heavily decomposed. Quartz is euhedral or subhedral, porphyritic (0.2–0.5 mm). The estimated quota of quartz is 25–30 vol. %. Macroscopically, there are pink-coloured inclusions of calcite."

Sample 88/07 is obtained by J. EFTEKHARNEZHAD and A. BEHROOZI from the green clastic rock sequence as exposed in the gorge north of the Aghdarband village. Two slides of the ground mass yielded (E. KIRCHNER):

○ Slide No. 1

"The finer grained portion consists partly of rounded, but also of angular components (0.5–1.0 mm in diameter). The coarser components are between one and several centimeters in diameter. Quartz being the most frequent mineral constituent is to be found either as individual crystals – often furrowed by corrosion or by expansion cracks – and as microcrystalline quartz. The appearance of albite is similar: rounded or oblong-shaped rock components containing felspar laths of various size. Greenish-coloured chlorite is present, also pumpellyite; carbonate (calcite). The structure of a plutonic rock is discernible in a larger, rounded component, which now consists of compact brown coloured material (limonite), being not resolvable by optical means. The rock is a volcaniclastic sedimentary rock, i.e. a t u f f i t e."

○ Slide No. 4

"The almost jointless arrangement of angular and sometimes rounded grains imparts the impression of a 'crystal mush'. The components are prevailingly quartz (as monocrystals but also poly-crystalline). Additionally can be found albite; fragments of volcanic rocks being fine-grained to vitreous are found as well. Recrystallization took place at the grain-boundaries – mostly quartz-crystals which may encrust also other quartz grains. Chlorite is present, though extremely rarely.
It is a t u f f i t e *consisting of crystals and rock-fragments."*

Sample 76/51, finally, was collected by the author from a volcanic interlayer in the Upper Devonian limestone at the junction of the Kal-e-Anabeh stream with Kashaf Rud (fossil locality No. 41). E. KIRCHNER's diagnosis:

○ Slide No. 5

"A sedimentary rock as described in the case of slide No. 4. The quota of groundmass – i. e. the fine-grained portion (0.2–0.8 mm) – is higher than in slide No. 4; pebbles of quartz may be up to 5 cm in diameter.
The components are generally angular, respectively slightly rounded at most. The texture may be characterized as a 'crystal mush', since the even grained quartzes and felspars stick together very close, so there is only little space left for a matrix.
The quartz-crystals show corrosion or expansion-cracks; they make up about 50–60 vol. %. Mica and carbonate are found in the groundmass; their quota is higher than in slide No. 4. The ores are pyrite and chalcopyrite".

So, partly the "diabase" is slightly altered dacite to andesite and partly a volcanogenic sedimentary rock containing abundant quartz and albite, therewith pointing to a rather acidic volcanism in the neighbourhood.

Of special interest are slides No. 4 and 5, which show that a "crystal mush" occurs in the ground mass of the green clastic sequence as well as interlayered with the thin-bedded dark grey conodont bearing limestone. This suggests that a "crystal rain" fell repeatedly in this marginal part of the Upper Devonian ocean.

Looking for a Late Devonian acidic volcanism in southern Asia, we encounter the well known Devonian orogenic volcanism of Kasakhstan (cf. A.M. KURCHAVOV, 1985). There, a Middle to Late Devonian volcanic sequence starts with basalts and ends with widely spread products of rhyolitic eruptions. This violent volcanism may have been the source of volcaniclastics of Aghdarband. However, detailed petrological and petrochemical comparisons have yet to prove – or to disprove – this assumption.

In the parautochthonous part of the Caucasian Forerange the probably Frasnian Kartdzhurskaya suite resemble highly our Frasnian dark green volcaniclastic sequence of Aghdarband. We owe a precise description of this suite to A.A. BELOV, M.L. SOMIN and Sh.A. ADAMIYA (1978, p. 166): the suite

" ... is composed of various tuffs, tuff-sandstones, tuff-siltstones and tuff-conglomerates. Less frequent are clay- and siliceous shales, sandstones, limestones and effusives (plagioliparitic porphyries, quartz keratophyres). The tuffs are of the acid composition ... "

and further:

" ... The lower subsuite is composed of tuffs of various composition, acid effusives, siliceous shales, jaspers, claystones, less frequently effusives of the basic and median composition and lenses of limestones being frequently recorded as well ... "

Even a conglomerate at the base of the Tournaisian, containing limestone pebbles with Upper Fammenian microfossils is also recorded from the parautochthonous Caucasian Forerange.

This similarity of the Late Devonian volcaniclastic rocks exposed in the parautochthonous Forerange of the Caucasus to the Late Devonian volcaniclastic rocks of Aghdarband suggests that the region of Aghdarband, i. e. the basement of the Kopet Dagh, had had a similar Late Devonian history as the region of the Caucasian Forerange. This implies that the Devonian "Crimean–Caucasian Geosyncline" (N. TICHY, 1967, Fig. 1) does not wedge out within the Caspian basin (cf. Sh. ADAMIA et al., 1981, p. 438), but has an eastern continuation in the basement of the Kopet Dagh. However, this has also to be yet verified by suitable petrological and petrochemical comparisons.

Finally, also a comparison with late Devonian volcanic rocks of the Southern Tien-Shan Range is desirable (cf. V. D. BREZHNEV et al., 1967).

5. The Southern Frame

The steep and rocky slopes bounding the Aghdarband region to the southwest consist of slates, sandstones and conglomerates (Fig. 38); no carbonate rocks are exposed there, except for a few slivers which are tectonically interposed. The prevailing colour of the rocks is red, though some green or greenish colours are also present. No indicative fossils were found in these rocks which show – like those of the Northern Frame – symptoms of a low grade metamorphism.

Fig. 38.
The Southern Frame.
View from Aghdarband towards south.
SMF = Southern Main Fault; CZ = crush zone.

This Southern Frame of the Triassic is an imbricated fault zone, and the south-western boundary of the Triassic rocks is the Southern Main Thrust Fault. Five thrust slices (tectonic units) are discernible as far as the mapped area is concernd, by their specific rock composition as well as their tectonic position.

Since the rocks of the lowermost thrust slice (Unit I) are badly shattered and sheared, a description of the imbricate structure should preferably start at its top.

Unit V

(Cross-sections A, B, C, D, E, Pl. 4)

consists of a hard quartzitic sandstone (No. 40 on the map, Pl. 1)., Its colour is pale violet-red ("wine-red") and partly almost white (e. g. close to P. 1528 in the western part of the mapped area). The edge of the high tabelland south of Aghdarband, and its precipice towards north consists of this hard, red sandstone (Fig. 51). Basal parts of Unit V contain layers of purple-coloured conglomerate. Like the sandstone, the conglomerate is hard, breaking across the pebbles when hammered. Red sandstone, red and white quartzite, and diabase are the main components which extend up to fist-size. A few pebbles of red granite were also observed. Blocks of red conglomerate were found at the head of the Kal-e-Jom'eh valley containing pebbles of red and green coloured jasper. All components are well rounded in these layers of conglomerate at the base of Unit V.

Layers of conglomerate are also interbedded with the light reddish-white coloured sandstone of the upper parts of Unit V. This is the case in the western part of the mapped area, east of P. 1528. Pebbles of red quartzporphyry and crystalline limestone were observed there. Similar layers of conglomerate are also exposed farther to the south-east, in the region south of Aghdarband village, but outside the southern part of the mapped area, close to the highest elevation of the plateau (P.T.8, NIOC-TTT-J2, 1732 m). They contain pebbles of white and red quarzite, red porphyry and white quartzporphyry. Dykes of diabase cutting beds of quartzitic sandstone and conglomerate were noted at roughly this elevation.

Unit IV

(Cross-sections B, C, D, Pl. 4)

is composed of two rock types: the base of this thrust slice is a very hard, quartzitic, light green or greenish-grey coloured sandstone (No. 38 on the map). It is generally coarse-grained, but there are also layers of fine-grained sandstone, siltstone, and even sandy slates. Like the red sandstone of Unit V , this green quartzitic sandstone forms the rocky precipices and sheer rock-faces in the slopes south of Aghdarband; the sandstone thins out towards the south-east.

At its top this green sandstone changes into purple (violet-red) slates (No. 39 on the map), the sandstone-layers alternating with green and purple slates. The purple slates show scales of sericite along their s-planes.

These purple slates are very uniform and form the flat slopes above the precipices composed of the green sandstone. Traces of copper minerals were found in these slates at the head of the Kal-e-Jom'eh valley.

Unit III

(Cross-sections D, E, F, Pl. 4)

is a sheet of sericitic slates (No. 37 on the map), which – except for their predominant green colour – resemble the slates of Unit IV. They are separated by shear planes from the sandstones of Units IV and II.

Unit II

(Cross-sections D, E, Pl. 4)

also consists of one rock-type only. It is a hard violet-red coloured sandstone, which closely resembles the sandstone of Unit V. The prominent rocky spur of Kuh-e-Palang (P. 1297, SW of Aghdarband village [Figs. 39a and b]) is built up of this sandstone, which gradually thins out towards the south-east. A number of layers of conglomerate are also interbedded with this sandstone. However, the conglomerate, shown on the map south-east of Kuh-e-Palang at the base of Unit II probably belongs to Unit I.

The thrust slices V, IV, III and II are obliquely arranged in a SW–NE direction, "en echelon" one below the other, together forming a larger thrust sheet; it rests on Unit I at a major thrust plane striking more or less E–W (cf. geological map, Pl. 1).

a)

b)

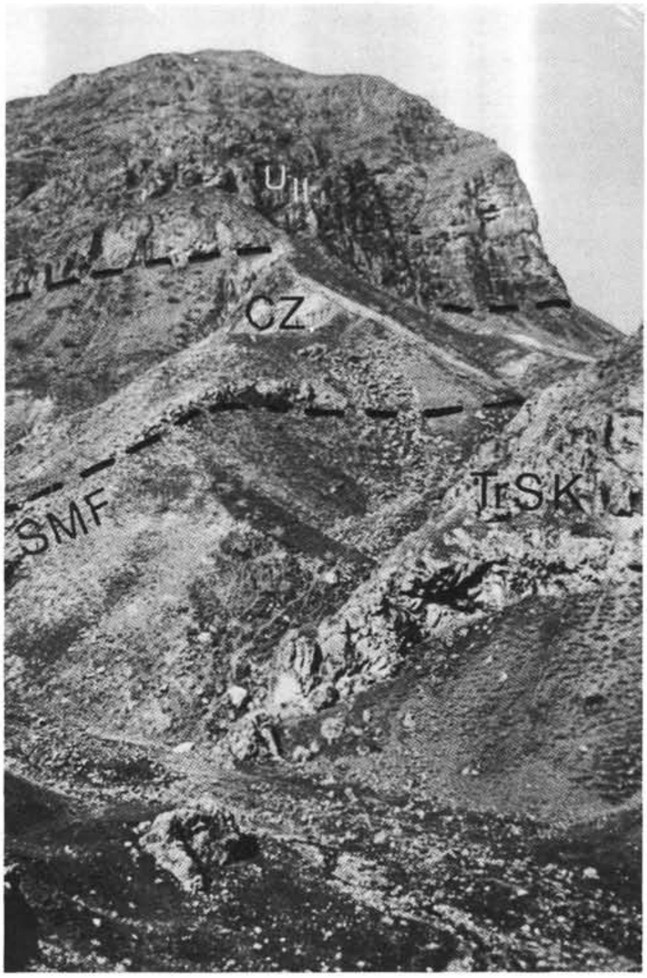


Fig. 39.
Kuh-e-Palang.
a) Units II and III.
b) Thrust zone at the foot of Kuh-e-Palang.
SMF = Southern Main Fault; CZ = crush zone, Unit I; TRSK = Triassic Sefid Kuh Limestone.

Unit I

(Cross-sections A, B, C, D, E, F, G, I, Pl. 4)

is a tectonic miscellany of various sheared and partly shattered rocks (No. 32 on the map). These rocks are in part the same as exposed in Units V–II: i.e. hard quartzitic sandstones, violet-red or green in colour, and purple or green coloured sericitic slates. Some of the sandstone bodies contain layers of hard conglomerate. Even the transitional beds between the green sandstone and the purple slates of Unit IV are present (purple slates interbedded with green sandstone layers, 0.5–1.0 meters thick each).

Generally, these rocks occur as isolated elongated bodies, serveral tens of meters in size. However, there are also larger coherent rock masses. One of these is shown on the map (Pl. 1) in the western part of the mapped area (No. 33 on the map). It is a hard quartzitic sandstone accompanied by some slates, violet-red and partly green in colour, forming a conspicuous cliff one kilometer in length (cf. also cross-section No. 1, Pl. 2 and cross-section A–A', Pl. 4, respectively).

The bulk of Unit I, however, consists of soft shales, sandstones and conglomerates differring from the rocks of Units V–II not only by their softness but also by their brownish-red to brick-red colour. This difference in colour between Units V–II is striking when looking down towards north from the edge of the southern high tabelland. The brownish-red coloured rocks show a high degree of resemblance to the rocks of the Scythian Qara Gheitan formation.

This is particularly the case with the conglomerates (No. 34). They are poorly cemented, so that weathering causes the components to become loose. These components are large ranging up to head size and more, those extremely large being in general poorly rounded. The composition of the conglomerate is the same as that of the conglomerate of the Qara Gheitan formation; red granite and red quartzporphyry are characteristic components. Lenses or sheets of this conglomerate are tectonically interposed between shales, slates and sandstones. However, there are locations where a primary (sedimentary) unconformity between the slates and conglomerates seems to be still preserved (see Fig. 40).

Not only the Qara Gheitan formation but also rocks of the Aghdarband Group appear to be included in the tectonic mixture of Unit I. The conglomerate is accompanied at a few localities by greenish-grey sandstones and shales containing indeterminable brachiopods and plant remains, e. g. at fossil locality No. 82 to the south of Kal-e-Bast. A calcareous sample collected at this locality yielded a damaged specimen of *Neospathodus* cf. *triangularis* (D. DONOFRIO in A. BAUD, E. BRANDNER & D. DONOFRIO, this vol.), and is, most probably, a fragment of Sefid Kuh Limestone.

Such rocks, suspected to be Triassic, also occur in the immediate vicinity to the thrust fault which separates Units V–II from Unit I. One of these occurrences is shown on the map to the west of Kuh-e-Palang (No. 35); it consists of greenish-grey sandstone and shale and also contains indeterminable plant remains. Farther to the west (north-west of P. 1357), black coaly shales and greenish-grey sandstone are exposed in a mylonite-zone immediately below this thrust fault.

Thus, Unit I is obviously the basement complex of the Triassic Aghdarband Group, i.e. the overturned and sheared basement of the Aghdarband Syncline. It consists mainly of the Early Scythian Qara Gheitan formation but contains tectonic slices of the metamorphosed Units V–II of the Southern Frame, and very probably some chips of the Triassic Aghdarband Group.

The base of Unit I is a crush zone, which accompanies the Southern Main Thrust Fault along its entire length in the mapped area (No. 31 on the map). It consists mainly of shattered rocks of Unit I, but also occasionally contains elements of the Aghdarband Group. Two chips of Sefid Kuh Limestone are shown on the map at the southern (upper) boundary of the crush-zone which is a thrust-plane parallel with the Southern Main Thrust Fault. Another secondary thrust-plane branches off from the crush zone in the easternmost part of the mapped area, splitting Unit I there into two sub-units (cf. cross-section F, Pl. 4).

An attempt to trace the imbricate structure of the Southern Frame beyond the mapped area to the south-east was made with the aid of air photos and based on the geological evidence provided by J. EFTEKHARNEZHAD & A. BEHROOZI; it is shown on the structural sketch map Fig. 1. Large bodies of both, Sefid Kuh Limestone and

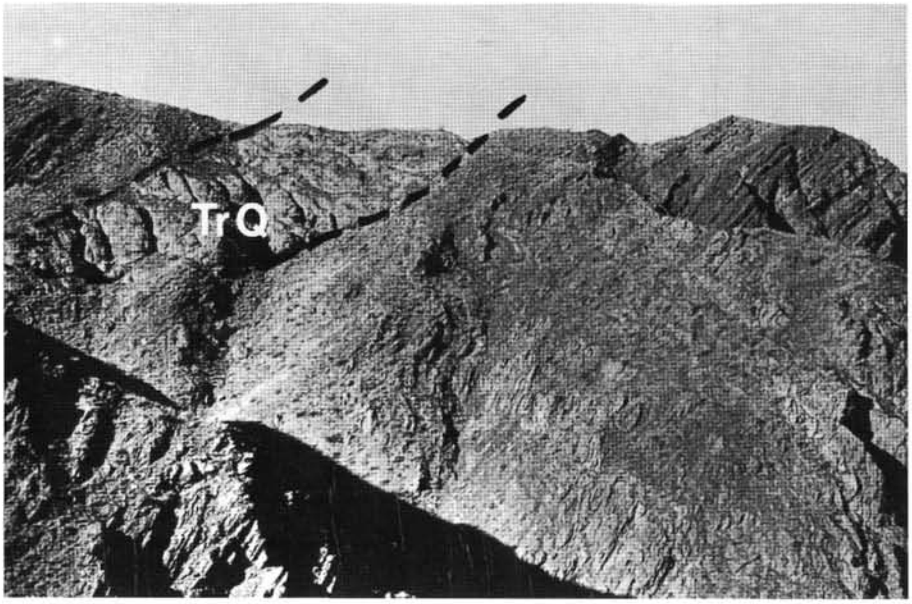


Fig. 40.
The Southern Frame, Unit I: Tectonic inclusion of unmetamorphosed Qara Gheitan Conglomerate (TrQ) in weakly metamorphosed slates and sandstones; unconformity below the conglomerate.
Kal-e-Bast area.

Carboniferous Limestone, are parts of this structure in the area NE of the village Shahtutak. The panorama photo Fig. 50, taken from the north, shows clearly the imbricate folding in front of the thrusting.

The age of the hard quartzitic sandstones and sericitic slates composing Units V–II and which are also present in Unit I, is not known. These rocks are slightly metamorphic – like those of the Northern Frame – and are completely barren of fossils. The violet-red sandstones of Units V and II, and the purple slates of Unit IV resemble lithologically the Lalun Sandstone and the Saigun Formation respectively of the Alborz Mountains (A. RUTTNER, 1983, 1984). On the other hand, A. BEHROOZI and J. EFTEKHARNEZHAD (this vol.) are inclined to regard these rocks to be parts of the Qara Gheitan formation which have been metamorphosed for some reason and thrust northward over the rocks of the Aghdarband Group. Indeed, the composition of the conglomeratic layers in these sandstones is strikingly similar to that of the conglomerate which is part of the Qara Gheitan formation.

Here again, a comparison with the parautochthonous Caucasian Forerange may serve for a better understanding. According to A.A. BELOW, M.L. SOMIN and Sh.A. ADAMIYA (1978), the Upper Paleozoic deposits of the Forerange (and also of a part of the Precaucasus)

" ... *form a typical Hercynian orogenic complex of continental molassa and volcanic rocks* ... " (p. 169).

Piles consisting of conglomerates, sandstones, siltstones, claystones, locally interbedded coal beds, and associated volcanic rocks represent the Namurian and Westphalian. Thick deposits of continental volcanogenic-terrigenous rocks are of Permian age. The latter are partly (e.g. the Kinyrchadskaya suite)

" ... *characterized by imbricate occurrences characteristic of rocks of the piedmont slopes. The suite is composed of typical red coarse-detrital molassas: conglomerates, sandstones, less frequently siltstones, claystones and volcanogenic rocks* ... " (p. 171).

The imbricate structure of Units V, IV, III and II of the Southern Frame at Aghdarband may be also of such an origin.

Further (p.171/172):

" ... *Besides the above red Permian deposits, there are in the Forerange thick (from 1000 to 3000 m) red terrigenous accumulations containing in the upper part in conglomerate pebbles of limestones with foraminifers of all Permian zones of the Tethys, including the uppermost ones. The palynological studies of the last years (data by I.I. GREKOV) confirmed the Triassic age of these red deposits* ... "

This is exactly the Qara Gheitan formation to the south of Aghdarband (cf. next chapter).

In Unit I the metamorphic clastic rocks of the Southern Frame are tectonically mixed with unmetamorphosed clastic rocks of the Qara Gheitan formation. This suggests that the former represent an older – slightly metamorphosed – part of the "Hercynian molassa" of the Russian authors. This in mind, and in view of the rock sequences reported from the Caucasian Forerange, the red/green rocks of Units V–II of the Southern Frame are considered now to be the primary (?Permian) substratum of the early Scythian Qara Gheitan formation, as shown in the general cross-section Fig. 41.

6. Outlook to the South

(cf. general cross section, Fig. 41
and structural sketch map, Fig. 1)

Recent fieldwork carried out by a GSI-team renders possible a general view of nearly the entire erosional Window of Aghdarband (cf. J. EFTEKHARNEZHAD & A. BEHROOZI, this vol.) and, with that, an insight into the regional position of the Triassic of Aghdarband.

The Shahtutak Fault bounds the Southern Frame of the Triassic to the south. Being clearly discernible on the air photos and on the Landsat images, this Fault is probably the most important one of the area. A. BEHROOZI found along this Fault elongated bodies of recrystallized limestone similar to the Carboniferous Limestone – however suspected now to be Triassic limestone – as well as rocks comparable to the Upper Devonian rocks of the Northern Frame. Differently from all other Cimmerian structures of the area, this Fault affects also the Jurassic coverbeds of the Window, i. e. the Kashafrud and the Mozdaran Formations (cf. the structural sketch map, Fig. 1). Most probably, the Shahtutak Fault is a side slip fault, like the Northern Main Fault.

The spacious area, extending to the south-west of this Fault, has a monotonous appearance on the air photos. J. STÖCKLIN and M. DAVOUDZADEH traversed this area in spring 1972. According to the notes in STÖCKLIN's fieldbook, the entire area up to the southern border of the Window consists of red and partly (in the lower part) green coloured shales, siltstones, sandstones and conglomerates. The layers of conglomerate outcropping at the southern slope of the flat upland area which extends to the south of Aghdarband contain limestone pebbles; some of them show traces of crinoids and corals, pointing to a late Paleozoic (?Carboniferous) age of the limestone (personal communication of STÖCKLIN). This is now confirmed by F. KASHANI (in EFTEKHARNEZHAD & BEHROOZI, this vol.), who found an assemblage of microforaminifera in such limestone pebbles which point to a Carboniferous age of the limestone as the source of these pebbles. One pebble yielded late Permian microfossils.

This sequence of unmetamorphosed red (and partly green) coloured conglomerates, sandstones and shales exposed in the southern part of the Aghdarband Window is doubtlessly the equivalent of our Qara Gheitan formation as emphasized by J. EFTEKHARNEZHAD & A. BEHROOZI (this vol.). And it is, obviously, also the equivalent of the Traissic "thick terrigeneous accumulations" of the Caucasian Forerange as cited above.

Close to the south-western edge of the erosional Window, i.e. in the area of Darreh Anjir, the Qara Gheitan formation borders on ophiolitic rocks, consisting partly of ophiolitic mélange (composed of diabasic rocks, radiolarite, radiolarian chert, siltstone, etc.) but also comprising ultrabasic rocks, gabbro, phyllitic shales, and recrystallized limestone (EFTEKHARNEZHAD &

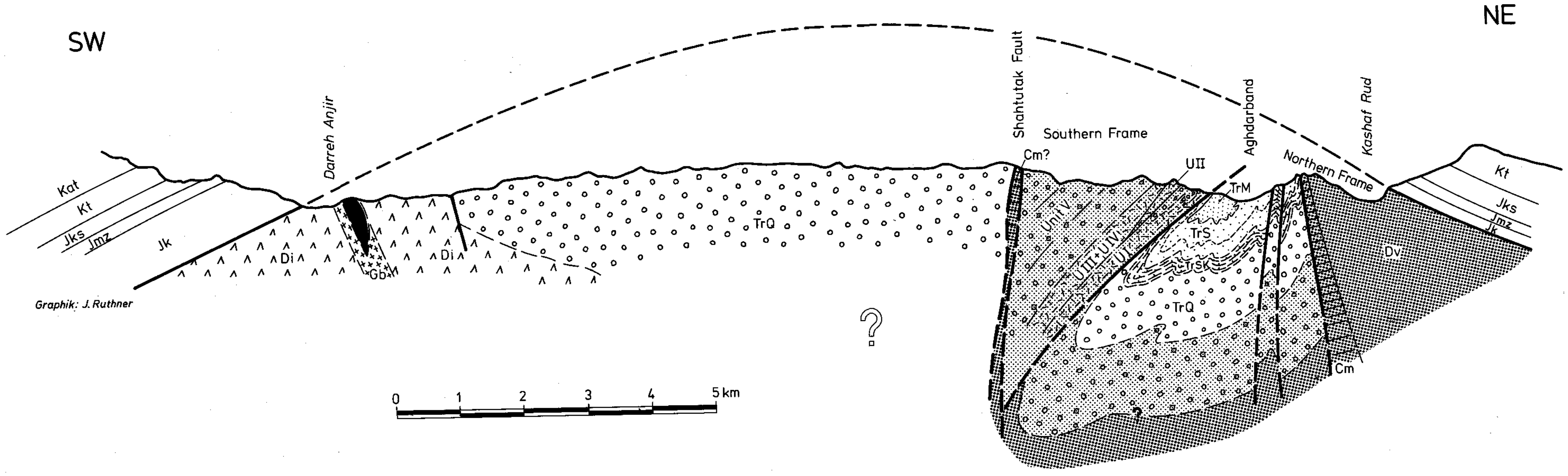


Fig. 41.
General cross-section through the Erosional Window of Aghdarband.
Legend see Fig. 1, pp. 18/19.

BEHROOZI, this vol.). In this limestone F. KASHANI and F. BOZORGNIA found a late Permian microfauna. These ophiolites represent evidently the northern extension of the Permian ophiolites of the Fariman area (cf. EFTEKHARNEZHAD & BEHROOZI, this vol.) cropping out here again below their Jurassic coverbeds.

The contact between these ophiolitic rocks and the Qara Gheitan formation is faulted mostly. But at one site EFTEKHARNEZHAD & BEHROOZI found a sedimentary transgressive contact of the Qara Gheitan formation on ultrabasic and gabbroid rocks; this evidence is sustained by finds of subrounded pebbles, consisting of basic and ultrabasic rocks and radiolarian chert, in the basal conglomerate of the Qara Gheitan formation. On all these grounds, an Early Scythian age can be assigned to the Qara Gheitan formation.

So, the Shahtutak Fault separates two areas which differ thoroughly from each other. To the north of the fault there is the Aghdarband area proper characterized by its specific Triassic sequence and by its slightly metamorphosed Paleozoic rocks; to the south, however, there are the remains of a Permian ocean floor. The Early Scythian red clastic rocks of the Qara Gheitan formation rest on both, on the Paleozoic rocks of Aghdarband as well as on the ophiolites of Darreh Anjir.

7. The Structure of the Triassic

The present-day structural features of the Triassic part of the Aghdarband area are the result of the Early Cimmerian Orogeny, which occurred during latest Triassic times. All these features are covered by flat-lying beds of the Kashaf Rud Formation, which are, in the main, late Bajocian – Bathonian in age (M. MADANI, 1970); the youngest beds still included in these structural features are those of the Norian–Rhaetian Miankuhi Formation. The probably Rhaetian Ghal'eh Qabri Shale Beds are already deposited after the Early Cimmerian Orogeny.

The Alpine Orogeny merely resulted in a gentle doming, followed by a general uplifting of the area.

Squeezed between the Northern and the Southern Frames, the rocks of the Aghdarband Group (and also those of the Qara Gheitan formation) are strongly deformed. This deformation is mainly such of a plastic type. There are folds at all scales ranging from several hundred meters down to only a few meters. One of the most interesting experiences during the mapping programme was to observe these indications of an extreme plasticity in the Sefid Kuh Limestone as well as in the shales and sandstones of the Sina Formation. The diagenetic consolidation of the Triassic sediments had obviously not been completed by the time deformation took place.

A detailed study of kind and scope of this deformation was necessary in connection with the evaluation of the coal deposit. Additionally, extensive measurements, combined with a detailed mapping, resulted in a better understanding of the general tectonics of the area. This may account for the number of Diagrams in the structural description of the area.

Faults are, nevertheless, a prevailing trait of the structure at Aghdarband. Major faults bound the Triassic in the north as well as in the south. Within the Triassic, three structural slices are separated from each other by faults, and the boundary between the Sefid Kuh Limestone and the tuffaceous beds of the Sina Formation is usually faulted as well.

Basically, the structure of the Aghdarband area is that of a large syncline. All of the three structural slices identified are part of this structure. However, there is considerable difference in structure between the area to the west of the Aghdarband village ("Miankuhi") and the area to the east of that village ("Nuhi"-"Sina").

Fig. 42.
View from the Southern Frame to the Northern Frame.
Northern Main Fault, view from south.
DV = Upper Devonian volcanogenic dark green rock sries; CM = Lower Carboniferous limestone; NMF = Northern Main Fault; Tr = Triassic of Aghdarband; UII = Unit II of the Southern Frame (Kuh-e-Palang); A = village of Aghdarband.
In the background the Jurassic–Cretaceous cover beds of the erosional window.

7.1. The Northern Main Fault

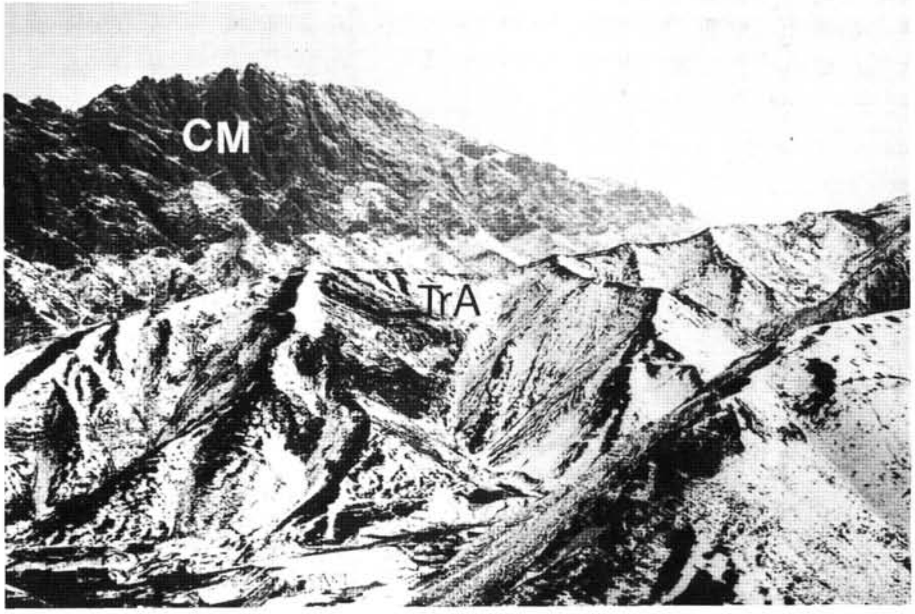
It separates the Triassic of Aghdarband from the Paleozoic rocks of the Northern Frame (Fig. 42). This is one of the major Early Cimmerian faults of the area; it is more or less vertical, or steeply inclined towards the north, and is conspicuous everywhere in the landscape, whether it separates the "marble" of the Northern Frame from Sefid Kuh Limestone or from the tuffaceous sandstone of the Sina Formation (structural Slice I). It is, very probably, a sinistral side slip fault (cf. chapter 7.6.; Fig. 43a).

The importance of this Fault is emphasized by outcropping wedges of rocks of the Qara Gheitan formation (red shale, sandstone and conglomerate) along the Fault in the region to the north and north-east of the Aghdarband settlement (Fig. 43b). A lens of Sefid Kuh Limestone was found to be accompanying these rocks of the Qara Gheitan formation at one location ENE of Aghdarband. A dark green-coloured basic volcanic rock, which also accompanies these tectonic wedges belongs very probably to those basic rocks which occur on top of the Qara Gheitan formation. A zone of shattered and crushed rocks may be seen wherever the Fault is well exposed.

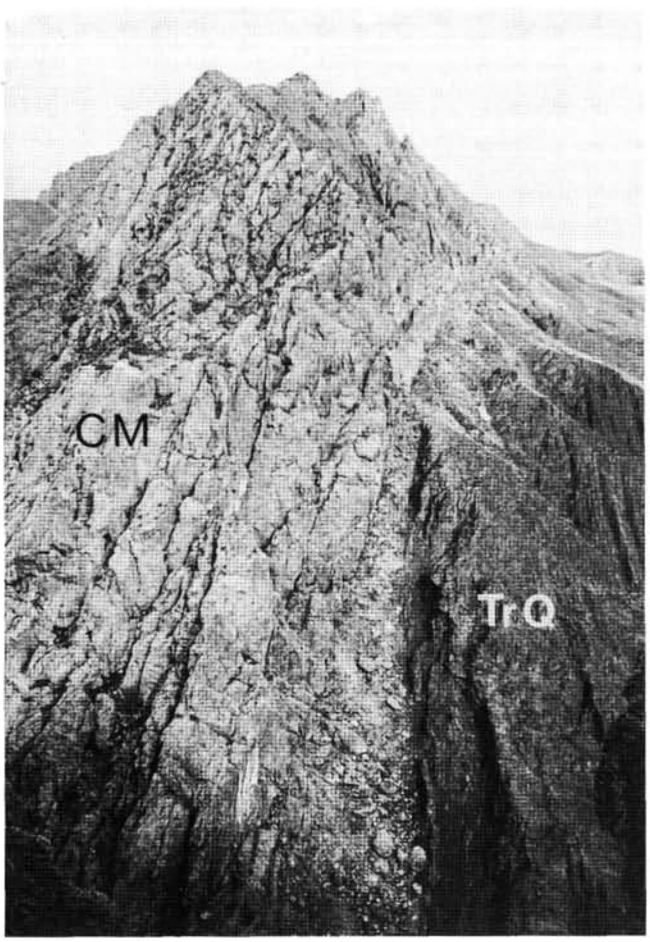
The Northern Main Fault disappears below the Rhaetian Gal'eh Qabri Shales towards the east (close to the Ghal'eh Qabri village) and below the Jurassic Kashaf Rud Formation towards the west (i.e. close to the west of the village Qara Gheitan).

Fig. 43.
The Northern Main Fault.
a) East of Aghdarband.
b) Tectonic insert of red beds of the Qara Gheitan formation (conglomerate and sandstone) along the Northern Main Fault north of Aghdarband.
CM = Lower Carboniferous limestone ("marble"); TrQ = Qara Gheitan formation; TrA = Triassic Aghdarband Group.

a)



b)



7.2. Structural Slice I

It is a narrow strip consisting of rocks of the Sefid Kuh limestone Formation, the Nazarkardeh Formation and the Sandstone Member of the Sina Formation; it stretches over the whole mapped area along the Northern Main Fault. To the west, beyond the mapped area (Qara Gheitan), the strip of Slice I becomes wider and more representative; shales of both the Shale Member of the Sina Formation and the Miankuhi Formation, and even the Aghdarband Coal Bed, are exposed there.

Slice I is a steeply upturned sequence of rocks throughout the mapped area and appears there to be the detached northern limb of the synclinal structure of Aghdarband. It is separated from Slice II by a vertical fault, or partly perhaps by a zone of vertical faults, the trend of which is more or less parallel with that of the Northern Main Fault. The fault is evident on both sides of the Aghdarband village – to the north-east and north-west of the village – separating there tuffaceous shale of Slice II from tuffaceous sandstone of Slice I.

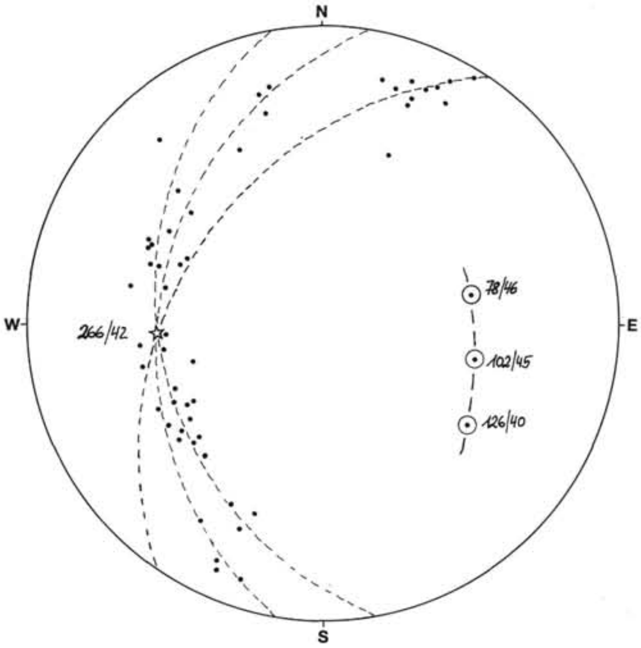


Diagram D_1.
"Onion-shaped" fold 650 m ENE Aghdarband village.
● 52 poles of bedding planes.
* Axis of rotation.
Schmidt projection.

From there the fault can be traced towards the east, but it is not possible to locate it exactly, because of the occurrence of tuffaceous sandstones of the Sina Formation at both sides of the fault. Difficulties in the evaluation of A. BAUD's Sina cross-section resulting from this ambiguity are noted in chapter 3.2.2.2. The structural sketch-map, Fig. 1, shows a possible course of this fault at the northern slope of the Ghal'eh Qabri valley; this is interpreted from air photos. However, the fault may also continue at the bottom of the valley, where the rocks show serious disturbance. Finally, there is also the possibility that Slice I wedges out just before reaching the Anabeh valley.

The westward continuation of the fault – or the faulted zone – separating Slice I from Slice II is not quite clear either. The fault, which can be observed to the west of the Aghdarband valley, seems to end in a narrow syncline between two anticlines, as shown on the geological map Pl. 1 and in sections 3 and 2 of Pl. 2; but it probably continues westward at the southern border of that syncline, i. e. along the border to the southern limestone anticline (cf. geological sketch map, Fig. 2). The northern border of this limestone is clearly faulted against tuffaceous sandstone in the Kale-Bast region (cf. Sections A–A' and B–B', Pl. 4).

Further west, a faulted zone, which crosses the Kal-e-Faqir valley east of Sefid Kuh, and another strongly disturbed zone, about 100 meters wide and separatiing rocks of the Aghdarband Group form those of the Qara Gheitan formation west of the Sefid Kuh Mountain, may be assumed to be the western continuation of the fault between the two slices.

On the whole, Slice I has the shape of an elongated wedge, which gradually thins out towards the east along the Northern Main Fault.

An east-plunging "onion shaped" fold of the order of several tens of meters was measured in tuffaceous sandstone about 650 meters east of Aghdarband village (cf. Diagram D_1). The average inclination of the axis of this fold is 45° towards the east (78/46 and 102/45); a third ESE plunging fold-axis can be traced from Diagram D_1 (126/40). The Diagram shows the poles of these three fold-axes placed in a great circle of the Schmidt-projection.

7.3. Structural Slice II

It is the central part of the synclinal structure of Aghdarband and comprises the complete rock sequence of the Aghdarband Group, including the Aghdarband Coal Bed.

The southern bounds of structural Slice II are thrust faults, i. e. the Southern Main Thrust Fault westward of the Aghdarband village, and the thrust of Slice III on Slice II eastward of that village. This is the reason for a considerable difference in the internal structure of Slice II between these two areas: west of Aghdarband, it consists of a wide ESE-plunging syncline, termed here the A g h d a r b a n d S y n c l i n e, which is accom-

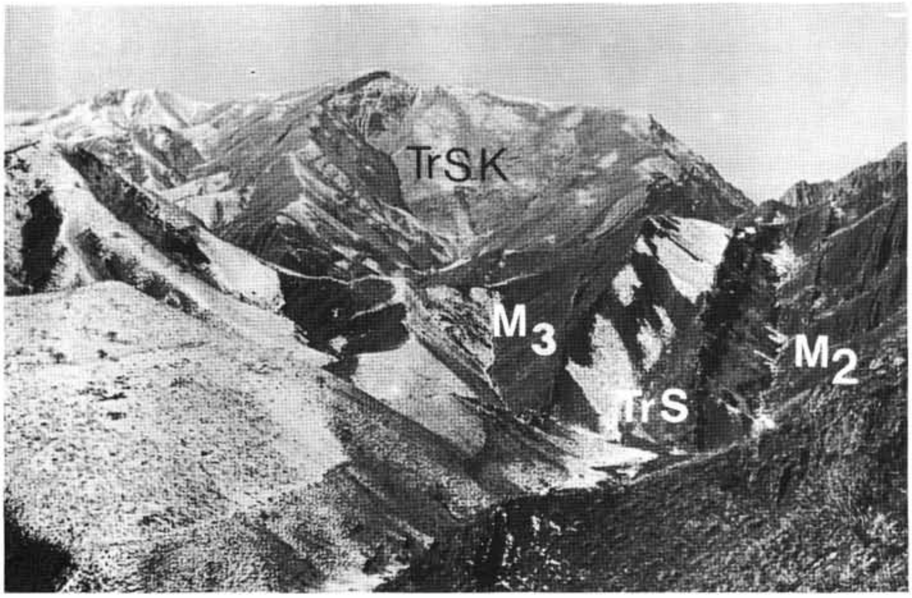


Fig. 44.
Sefid Kuh, seen from the east: eastwardly inclined dish of Sefid Kuh Limestone.
TRSK = Triassic Sefid Kuh Limestone; TRS = Triassic Sina Formation; M_2 = Sandstone Member; M_3 = Shale Member.
See also Figs. 7 and 13.

panied to the north by a narrow ESE plunging anticline, the Aghdarband Anticline; to the east of Aghdarband, the syncline becomes compressed and folded into serveral narrow secondary folds, and the accompanying anticline does not exist there any more.

7.3.1. The Western Part

To begin with, in the western part of the area, the Aghdarband Syncline is by far the dominating structural element (cf. cross-sections A–A' to E–E', Pl. 4, or sections 1–3, Pl. 2 respectively).

The core of the syncline contains the shales of the Miankuhi Formation; older beds of the Aghdarband Group appear at the surface gradually towards the west in synclinal flexures, in accordance with the general ESE plunge of the synclinal axis. The bottom of the syncline is represented by the Sefid Kuh limestone Formation, in the shape of an eastwardly inclined dish at the Sefid Kuh Mountain west of the mapped area (Fig. 44); the Scythian Qara Gheitan formation is exposed at the western side of that mountain (cf. structural map, Fig. 1; map of the northern part of the Window, Fig. 2 and Figs. 5 and 6).

The broad flexure of the Aghdarband Syncline is undulated into several secondary folds. Measurements carried out on these sub-folds indicate a general plunge of the Aghdarband Syncline within the range of 10° to 35° (medium 25°) towards ESE–SE.

This general plunge is clearly shown in Diagrams D_2 and D_4; both of them were measured on northern subfolds of the Aghdarband Syncline.

Diagram D_3, measured on a southern sub-fold in contorted shales on top of the litharenite of the Shale Member, Sina Formation, shows a similar, but somewhat gentler, main plunge of the fold axes (7/122, 16/130); there is also a gentle (25°) east-plunging axis,

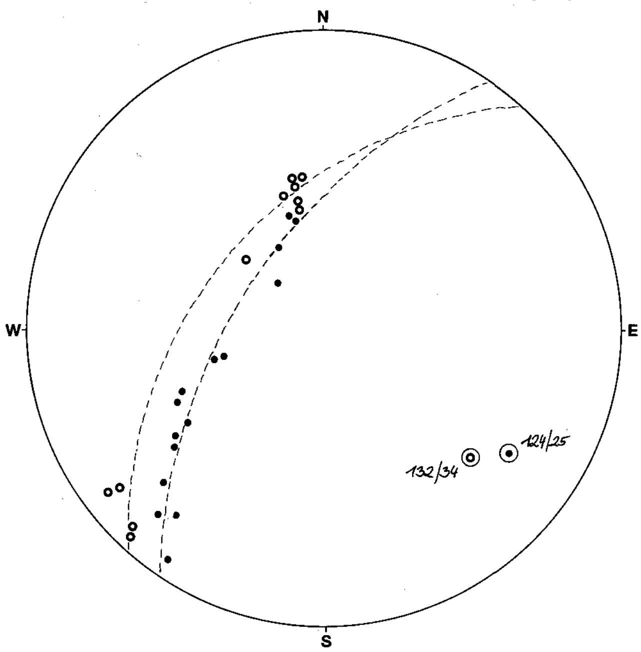


Diagram D_2.
Aghdarband Syncline, narrow sub-syncline.
Top of Sandstone Member of the Sina Formation; Kal-e-Faqir.
● Litharenite below Faqit Marl Bed, hinge of the syncline (15 poles of bedding planes).
○ Tuffaceous sandstone below litharenite (11 poles of bedding planes).
Schmidt projection.

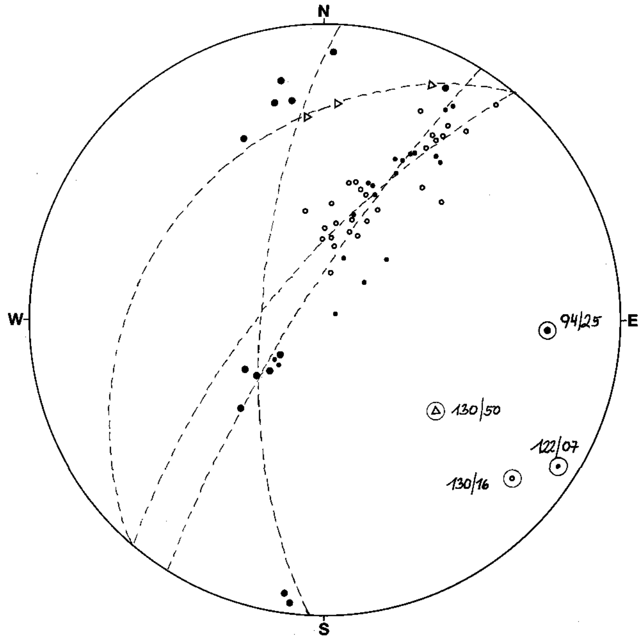


Diagram D_3.
Aghdarband Syncline, sub-syncline southwest of Kal-e-Bast.
Top of Shale Member, Sina Formation.
• ● Contorted shales below Coal Bed, core of the sub-syncline (32 poles of bedding planes).
○ △ Hinge of litharenite (30 poles of bedding planes).
Schmidt projection.

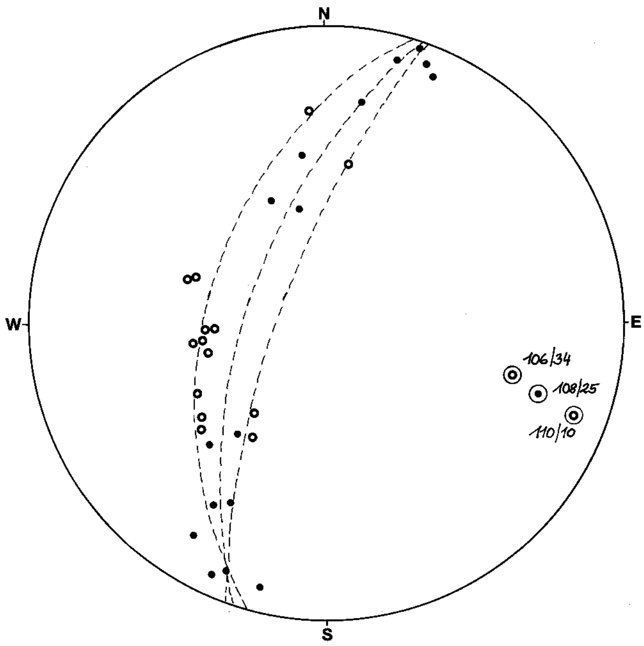


Diagram D_4.
Aghdarband Syncline, two sub-synclines of the Aghdarband Coal Bed.
South of Kal-e-Bast (cf. Plate 2, Section 1).
○ Narrow southern sub-syncline (15 poles of bedding planes).
● Broad southern sub-syncline (14 poles of bedding planes).
Schmidt projection.

and there are indications of a steeply (50°) plunging SE-axis.

The southern limb of the Aghdarband Syncline is overturned, reduced in intensely sheared below the Southern Main Thrust Fault. It is a jumble of rocks consisting mainly of parts of the Sina Formation and lentils of Sefid Kuh Limestone, which outcrop south of the

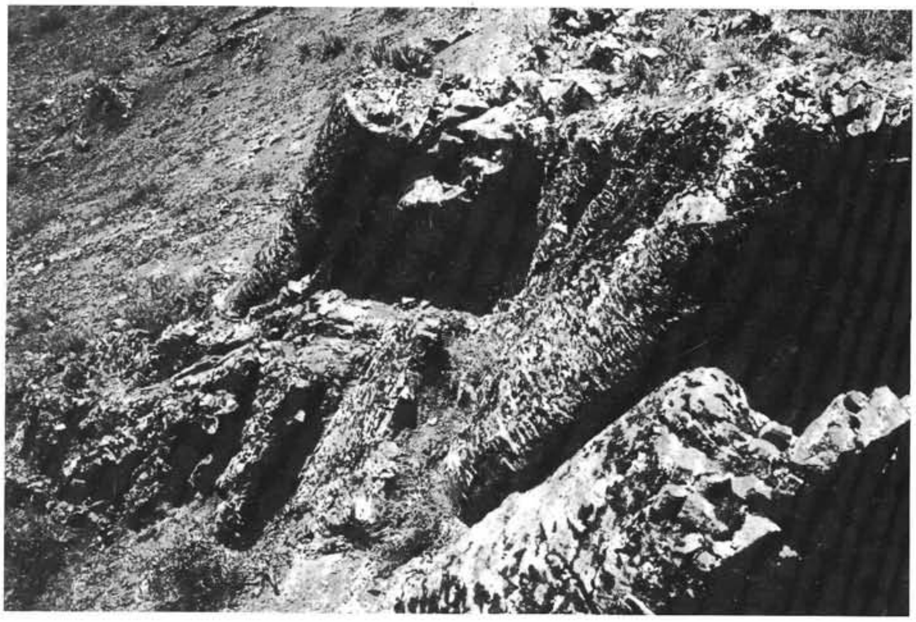


Fig. 45.
Extremely folded sandstone in shales of the Shale Member, Sina Formation.
Kal-e-Bast, Diagram No. 7.

shales of the Miankuhi Formation (core of the Aghdarband Syncline). The Aghdarband Coal Bed is preserved only locally at the southern border of these shales.

The hinge of this overfolding is exposed in the top-litharenite of the Sina Formation, between the western branch of the Kal-e-Bast valley and the eastern branch of the Kal-e-Faqir valley. The axial direction of this hinge is W–E (to WNW–ESE), with an inclination of 30° towards the east (cf. Diagram D_5). A fold in a litharenite in the southern limb of the Aghdarband Syncline, located 2.4 kilometers farther to the ESE (Diagram D_6), shows a plunge of 44° towards ESE (101°). At both locations, the axial direction of the overfolding of the southern limb is parallel to the trend of the Southern Main Thrust Fault; the axial inclination towards the east is somewhat steeper than the general axial plunge of the Aghdarband Syncline.

The northern limb of the Aghdarband Syncline is almost vertical. The Aghdarband Coal Bed was (and still is) mined there; the locations of the entries to Tun-

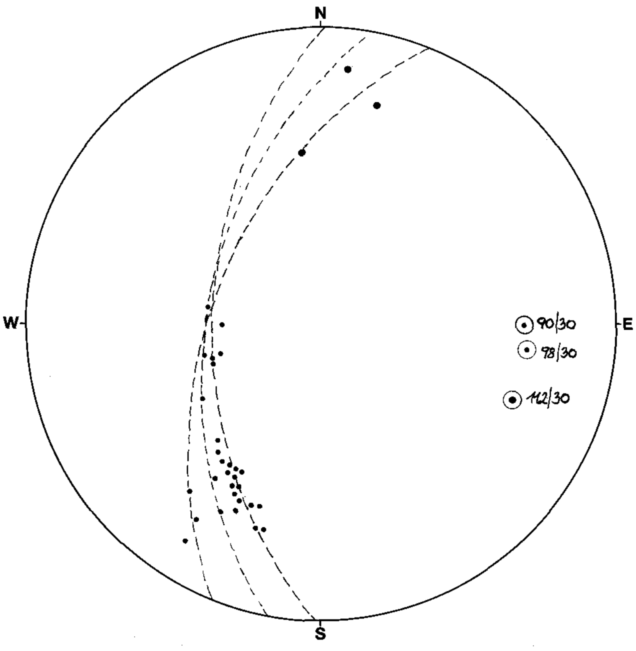


Diagram D_5.
Aghdarband Syncline, southern limb.
Top litharenite of the Shale Member, Sina Formation; W of the western branch of Kal-e-Bast valley.
• 29 poles of bedding planes.
● Tuffaceous sandstone immediately below the Southern Main Thrust Fault (3 poles of bedding planes).
Schmidt projection.

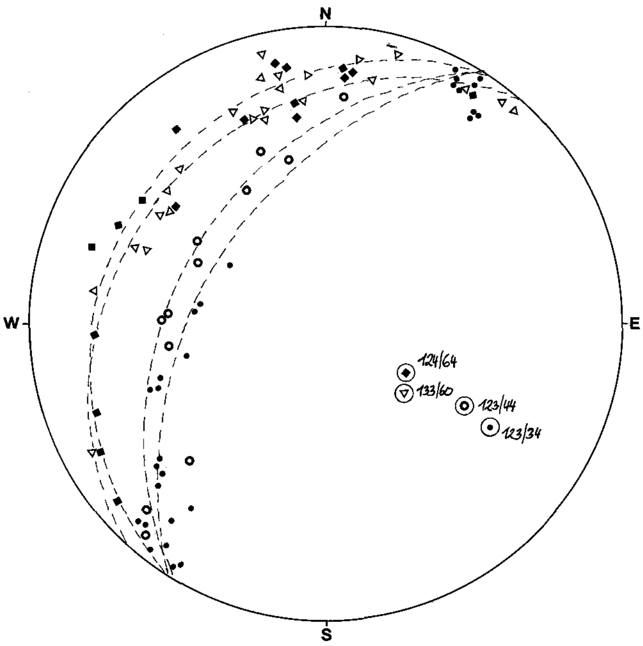


Diagram D_7.
Aghdarband Syncline, northern limb; cf. Fig. 45.
Extremely folded fine-grained sandstone embedded in the Shale Member, Sina Formation; Kal-e-Bast, west of fossil locality No. 79; four individual folds.
■ 18 poles of bedding planes.
△ 24 poles of bedding planes.
○ 12 poles of bedding planes.
● 28 poles of bedding planes.
Schmidt projection.

nels No. 4, 3 and 2 are shown on the geological map, Pl. 1. Exposures in the mine as well as those at the surface proved the existence of steep secondary folds at the northern limb of the Aghdarband Syncline (cf. geological map, Pl. 1 and Cross-sections 2 and 3, Pl. 2).

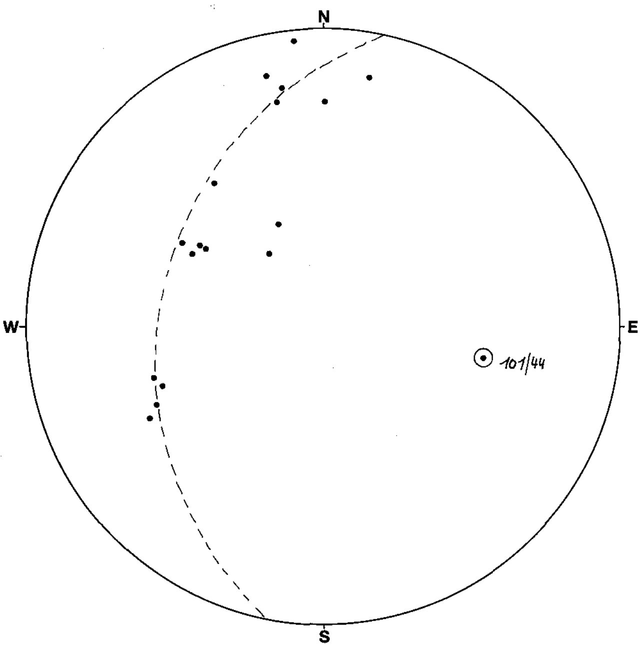


Diagram D_6.
Aghdarband Syncline, southern limb; cf. Fig. 25.
Tuffaceous sandstone below Southern Main Thrust Fault; east of Kal-e-Jom'eh valley.
● 17 poles of bedding planes.
Schmidt projection.

An impressive example of plastic deformation is shown in a layer of fine-grained sandstone (No. 12 on the map), which is embedded in shales of the Shale Member (Sina Formation). Fig. 45 imparts an impression of the plasticity of this sandstone layer, which seems to have been particularly sensitive to tectonic stress. These folds were measured at two localities in the northern limb of the Aghdarband Syncline: Just south-east of the synclinal flexure west of the Kal-e-Bast valley (Diagram D_7), and 900 meters farther to the south-east, east of the Kal-e-Bast valley (Diagram D_8, Fig. 25).

Diagram D_7 shows four individual folds. All of them have the same axial direction towards (E)SE (123°–133°); the angle of plunge, however, varies from 34° to 64°.

Diagram D_8 is also characterized by steeply pitching folds; the axes of three out of six measured folds plunge 42°, 50° and 68° towards the south (174° to 178°). But there are also three folds plunging gently towards ESE to SSE. The points of penetration at the orientation diagram (Schmidt net), pertaining to these three fold-axes, are arranged in a great circle, meaning that these axes are rotated around a rotation-axis inclined steeply (60°) towards the north. A look at Diagram D_8 imparts the impression as if the general gentle ESE-plunge of the fold-axes were rotated towards a southerly direction and steepened there to an inclination of nearly 70°.

The limestone range north of "Miankuhi" (P. 1200 – P. 1253 – P. 1246 – P. 1236 – P. 1208) is the core of the A g h d a r b a n d A n t i c l i n e. This limestone disappears east of P. 1208 below its cover-beds, which form the spectacular anticlinal structure west of Aghdarband village. The internal anticlinal structure of the limestone

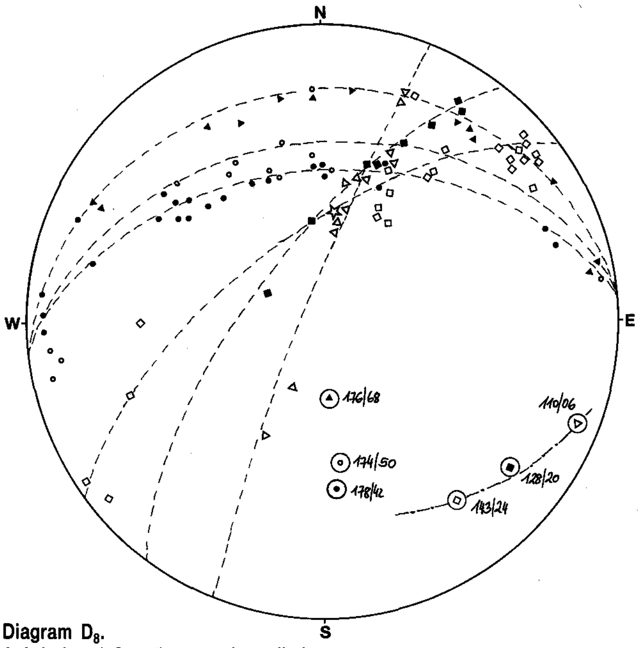


Diagram D_8.
Aghdarband Syncline, northern limb.
Folded finegrained sandstone embedded in the Shale Member, Sina Formation: Kal-e-Bast, south of fossil locality No. 86. Six individual folds.
▲ 13 poles of bedding planes.
○ 13 poles of bedding planes.
● 22 poles of bedding planes.
□ 23 poles of bedding planes.
■ 8 poles of bedding planes.
△ 12 poles of bedding planes.
* Axis of rotation.
Schmidt projection.

range is evident at places where the range is crossed by transversal valleys, e. g. Kal-e-Bast of Kal-e-Faqir.

This limestone range is bounded to the north by the fault (or fault-zone) separating Slice II from Slice I. The

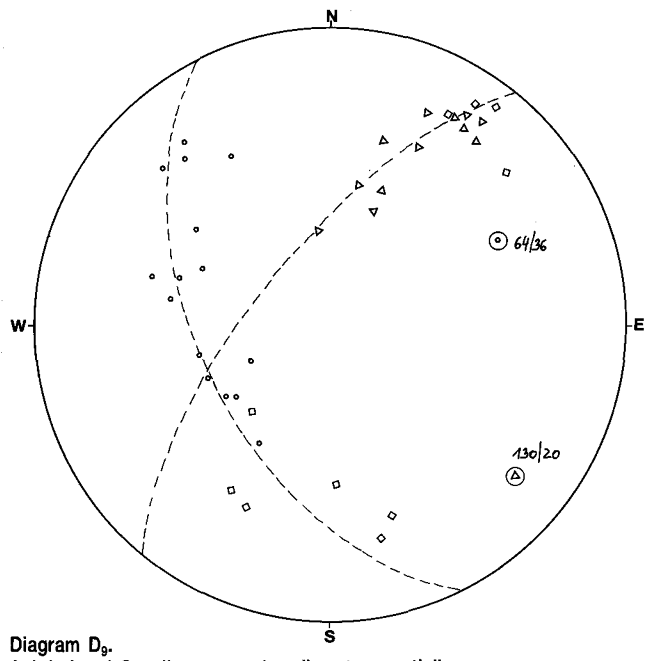


Diagram D_9.
Aghdarband Syncline, secondary limestone anticline.
Miankuhi, fossil locality No. 18.
△ Sefid Kuh Limestone, P. 1253 (12 poles of bedding planes).
□ Sefid Kuh Limestone (10 poles of bedding planes).
○ Coverbeds (sandstone, shale; Shale Member of the Sina Formation; 15 poles of bedding planes).
Schmidt projection.

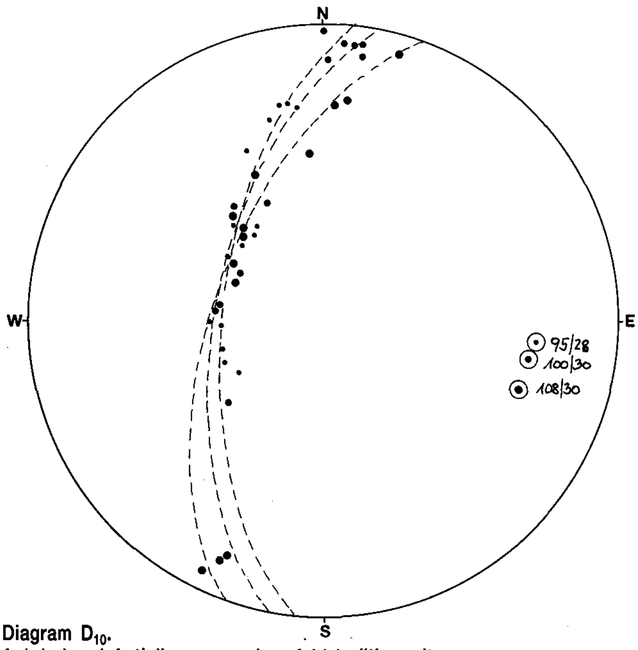


Diagram D_{10}.
Aghdarband Anticline, secondary fold in litharenite.
Top of Sandstone Member, Sina Formation, Miankuhi.
40 poles of bedding planes.
• Middle part of the fold (15 poles).
● Northern flank of the fold (16 poles).
● Southern flank of the fold (13 poles).
Schmidt projection.

southern flank of the limestone anticline is faulted against the northern limb of the Aghdarband Syncline (cf. cross-sections B–B', C–C', D–D', Pl. 4).

A secondary ESE plunging anticline branches off from the main limestone anticline at P. 1253, possibly parallel with a secondary ESE trending fault. This secondary anticline was measured at three locations:

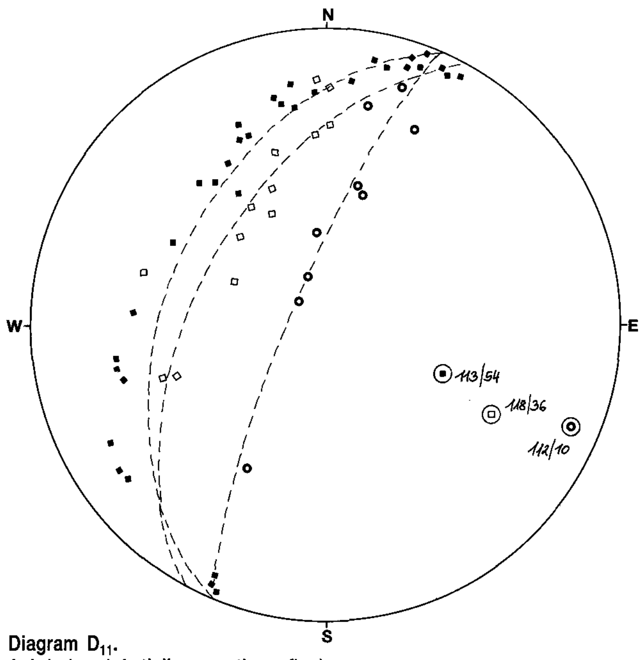


Diagram D_{11}.
Aghdarband Anticline, southern flank.
Three individual folds in shales of the Shale Member, Sina Formation; Miankuhi.
■ 33 poles of bedding planes.
○ 9 poles of bedding planes.
□ 13 poles of bedding planes.
Schmidt projection.

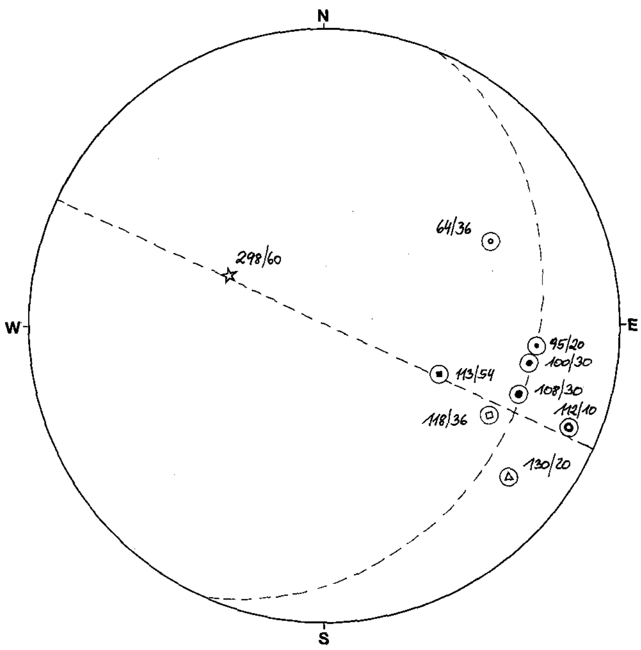


Diagram D_{9-11}.
Composite Diagram D_9, D_{10} and D_{11}.
Miankuhi.
* Axis of rotation.

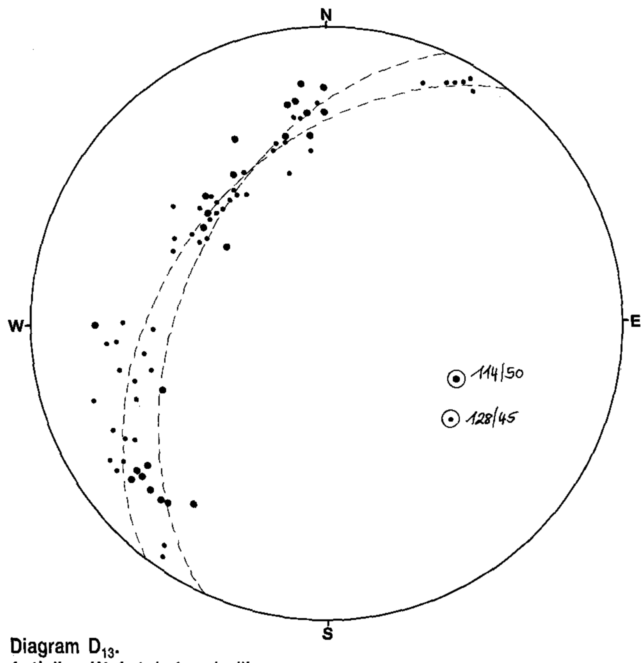


Diagram D_{13}.
Anticline W Aghdarband village.
Shale Member, Sina Formation.
• 49 poles of one single bedding plane of litharenite.
● Tuffaceous sandstone and shale, higher up (24 poles of bedding planes).
Schmidt projection.

Diagram D_9, at the spur of Sefid Kuh Limestone and its cover-beds ESE of P. 1253 (fossil locality No. 18), Diagram D_{10} 500 meters farther ESE in top-beds of the Sandstone Member and Diagram D_{11} again 400 meters farther ESE in shales of the Shale Member of the Sina Formation.

The three diagrams show a great variety of fold-axes, but when put together (Diagram D_{9-11}) they convey the same picture as in Diagram D_8: Gentle (20°–35°) plunging fold-axes rotated from ENE- to ESE-plunge around a steeply inclined rotational axis (in this case 60° towards WNW), and steepening there from an axial inclination of 10° to one of 54° towards ESE.

The Aghdarband Anticline terminates in the above mentioned anticlinal structure west of the Aghdarband village. Its general plunge there is 45°–50° towards ESE, which is well demonstrated in Diagram D_{13}. This is distinctly (by about 20°–25°) steeper than the general

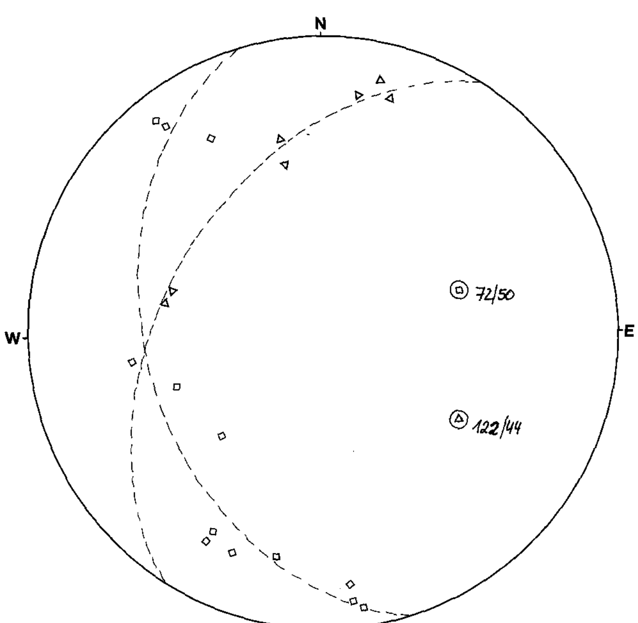


Diagram D_{12}.
Two folds west of Aghdarband village, west of the Site of Diagram 13.
△ Fold in litharenite 1400 m E of Aghdarband village; Shale Member, below the Coal Bed (7 poles of bedding planes).
□ Fold of the cover beds of the limestone anticline 1200 m WNW Aghdarband village (13 poles of bedding planes).
Schmidt projection.

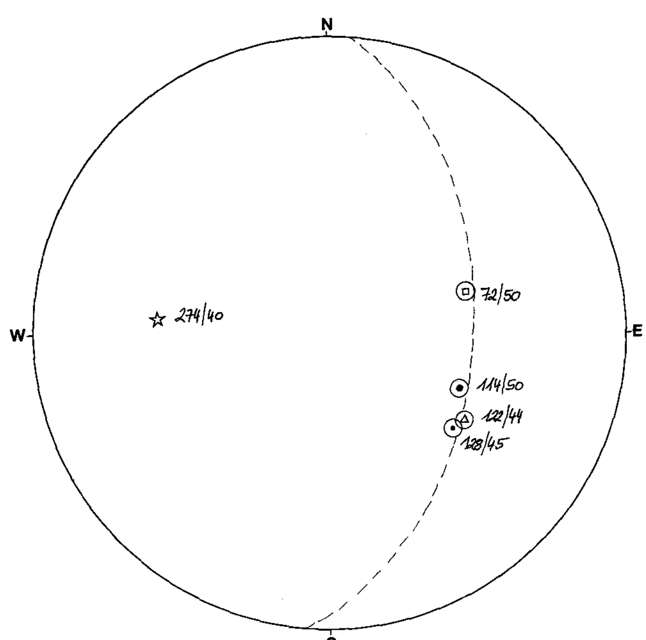


Diagram D_{12-13}.
Composite Diagram D_{12} and D_{13}.
Anticline west of the Aghdarband village.
* Axis of rotation.
Schmidt projection.

plunge of the Aghdarband Syncline at its synclinal turn in the Kal-e-Bast and Kal-e-Faqir region 6 kilometers farther west (cf. Diagrams D_2, D_3 and D_4).

The same steep ESE-plunge is displaced also by the fold of the thick litharenite 900 meters west of the site of Diagram D_{13}; however, 600 meters WNW of diagram D_{13}, at the site where the nose of the limestone range disappears below its cover-beds (see Fig. 10), the fold-axis of these cover-beds is steeply inclined towards ENE (cf. Diagram D_{12}).

A composite diagram of D_{12} and D_{13} again suggests the existence of a rotational axis, which this time is inclined by 40° towards the west.

7.3.2. The Eastern Part

In the eastern part of the area, Slice II reduces to a narrow strip, the result of the thrust of structural Slice III over Slice II (cf. cross-sections F–F', G–G', H–H', I–I', J–J' and K–K', Pl. 4).

The Aghdarband Anticline disappears already in the area west of the Aghdarband village. According to BRANDNER the Anticline is truncated there by a "sinistral oblique-slip fault" (cf. Addendum, chapter 10).

The wide Aghdarband Syncline becomes a narrow double-folded syncline whithin a short distance (cross-sections E–E' and F–F' are only 700 meters apart from each other!). Two (or respectively three) additional coal-bearing synclines appear parallel with and to the north of the main syncline; they were mined through the tunnels "Nuhi" and "Sina" (cross-sections 4 and 5, Pl. 2). All these synclines trend in WNW–ESE direction and outcrop towards the east (see geological map, Pl. 1 and cross-section K–K', Pl. 4).

The transition from the widely folded western section of Slice II to the narrow and intensively folded eastern section occurs in a narrow and highly disturbed region west and east of the Aghdarband settlement (cf. cross-sections E–E' and F–F', Pl. 4; see also chapter 10,

Fig. 46.
Zig-zag folds of the Coal Bed.
East of the Aghdarband settlement.

Fig. 47.
Recumbent fold of sandstone of the Sina Formation.
Hill just east of the Aghdarband settlement. In the background the Lower Carboniferous limestone ("marble") of the Northern Frame.

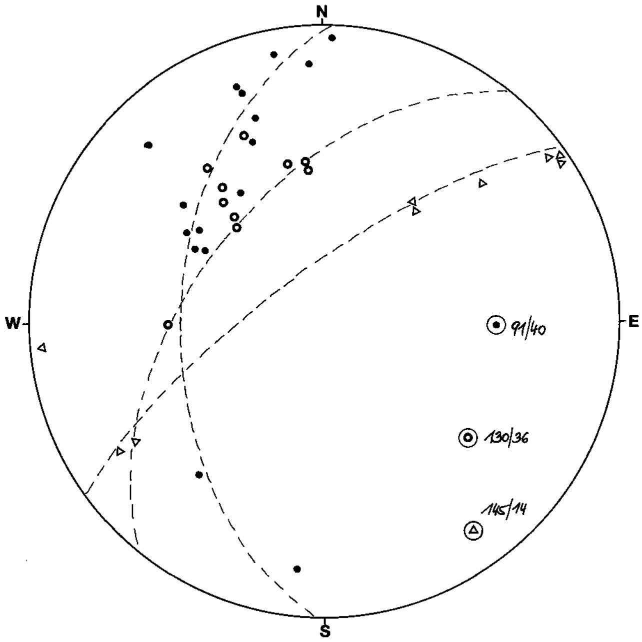


Diagram D_{14}.
Hill P. 1000, westward adjacent to the Aghdarband settlement.
△ Syncline ESE P. 1000; tuffaceous sandstone interbedded in shale of the Sandstone Member of the Sina Formation (9 poles of bedding planes).
● Fold WNW P. 1000; Hanging Sandstone of the Coal Bed (15 poles of bedding planes).
○ Hanging Sandstone of the Coal Bed, NW P. 1000 (9 poles of bedding planes).
Schmidt projection.

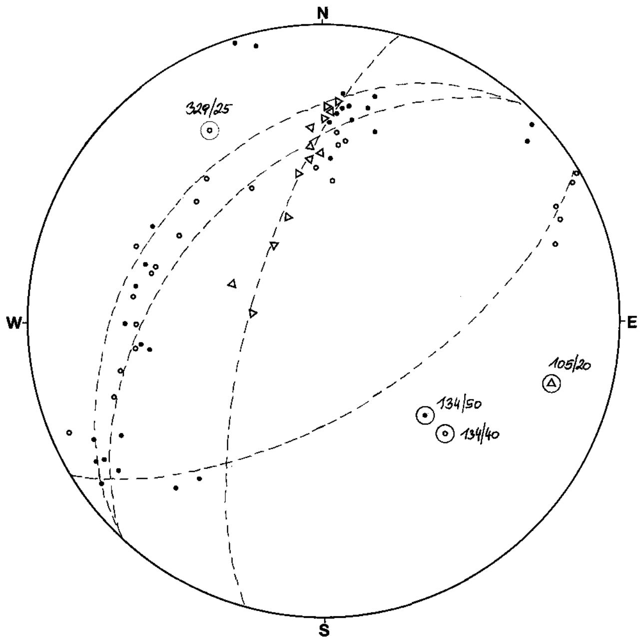


Diagram D_{16}.
Hill 800 meters E Aghdarband settlement.
Tuffaceous shale and sandstone, Shale Member, Sina Formation.
● Southern slope of the hill (28 poles of bedding planes).
○ Northern slope of the hill (23 poles of bedding planes).
△ Crest of the hill (13 poles of bedding planes).
Schmidt projection.

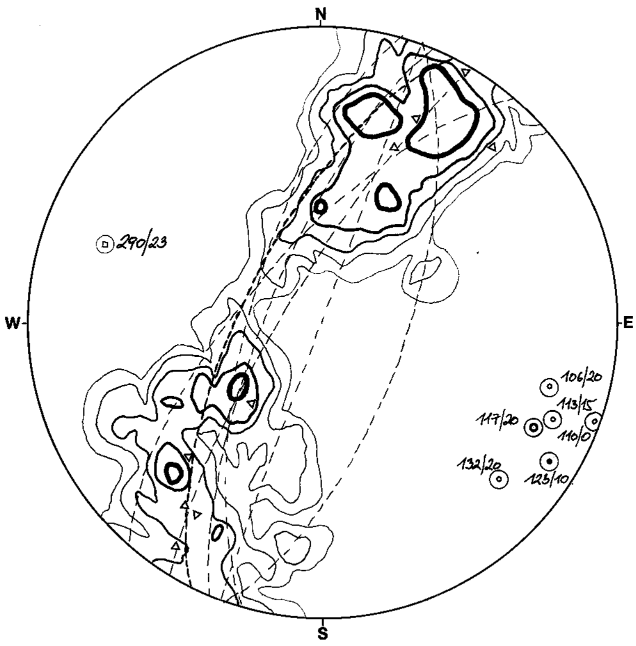


Diagram D_{15}.
Recumbent folds, hills just east of the Aghdarband settlement.
Shale and interbedded layers of fine grained sandstone, Shale Member, Sina Formation.
161 poles of bedding planes: >5.6 – 4.4 – 3.1 – 1.9 – 1.3 %.
○ 4 axes of individual folds.
△ 9 poles of bedding planes underground ("Gesenke").
● 1 axis underground ("Gesenke").
○ Average plunge.
□ West plunge?.
Schmidt projection.

Fig. 54). The Coal Bed is folded there in sharp zigzag-folds (Fig. 46); the beds are partly overturned towards the north, forming recumbent folds in the hill just east of the Aghdarband settlement (Fig. 47). This caused quite a lot of difficulties with regard to mining activities there.

Fold axes measured in this disturbed region testify to the abrupt change in the structural pattern. Steeply east (40°) and SE (36°) plunging axes are still present just west of the Aghdarband settlement (hill P. 1000, Diagram D_{14}) as they are in the anticline to the west of the settlement (cf. D_{13}). However, Diagram D_{14} also shows an axial direction which is gently inclined (14°) towards SSE.

Flatly (0°–20°) ESE to SE plunging axes are dominant in the overturned beds in the hill east of the settlement as well as in the "Gesenke" (winze) south-east of the settlement (Diagram D_{15}).

Flatly (0°–20°) ESE-SE plunging axes are again shown in Diagram D_{17} which was measured farther south-east, just to the north of (below) thrust sheet Slice III).

Steeply (40°–50°) SE plunging fold-axes prevail however in Diagram D_{16} measured in an aera close to the fault, which separates Slice II from Slice I. In addition, Diagram D_{16} shows also a flatly (20°) ESE plunging axis – corresponding to the general direction in Diagrams D_{15} and D_{17} – and an indication of an axis which is gently inclined (25°) towards the opposite side, i. e. towards NNW.

Lastly, Diagram D_{18} comprises surface measurements in the mining area between "Nuhi" (W) and "Sina". The Coal Bed is folded there into four, respectively three, narrow synclines (cf. cross-sections 4 and

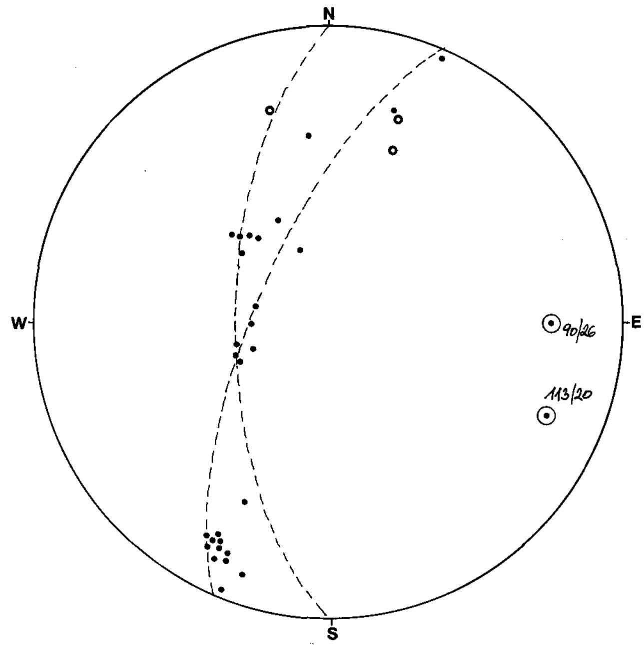


Diagram D_{17}.
Fold south of Tunnel "Nuhi"-West.
Coal Bed.
● 28 poles of bedding planes.
○ 3 poles of bedding planes.
Schmidt projection.

5, Pl. 2). The general trend of the fold-axes there is WNW–ESE. The direction of the plunge, however, changes from ESE in the western part of the synclinorium ("Nuhi") to WNW in the eastern part ("Sina"). This explains the termination of the coal-bearing synclines towards the east.

7.4. Structural Slice III

Structural Slice III and its thrust over Slice II is the cause of the strong deformation of Slice II in the eastern part of the area (see again cross-sections F–F' to K–K'; Pl. 4).

Slice III begins SSE of the Aghdarband settlement; it is steeply folded there into two anticlines and three synclines (cf. cross-sections F–F' and G–G'). The southern anticline consists of Sandstone Member of the Sina Formation and is a tectonic wedge below the Southern Main Thrust Fault, being separated from the northern part of Slice III by a minor fault.

Two of the synclines are evident in outcrops of the Faqir Bed, as shown on the geological map, Pl. 1; their cores consist of Shale Member, Sina Formation. The major syncline is the northern one; the minor syncline to the south-east is merely an infolding in the Sandstone Member. The axis of a small anticline in these sandstones south of the major syncline trends W–E and is gently inclined (14°–20°) towards the east. The axis of another small anticline in these sandstones plunges SE at 30° (Diagram D_{20}).

A third syncline is located close to the northern front of Slice III; it is uplifted by a fault and consists very probably mainly of the Sandstone Member of the Sina Formation, since *Traumatocrinus caudex* was found in the core of the syncline (fossil locality Nr. 29). The WNW–ESE trending axis of this syncline is actually horizontal; it is gently inclined towards ESE in the western part and gently towards WNW in the eastern part of the syncline (Diagram D_{19}).

As a result, the syncline narrows towards the east and an anticline develops at the northern flank of the syncline which becomes a typical front-anticline of

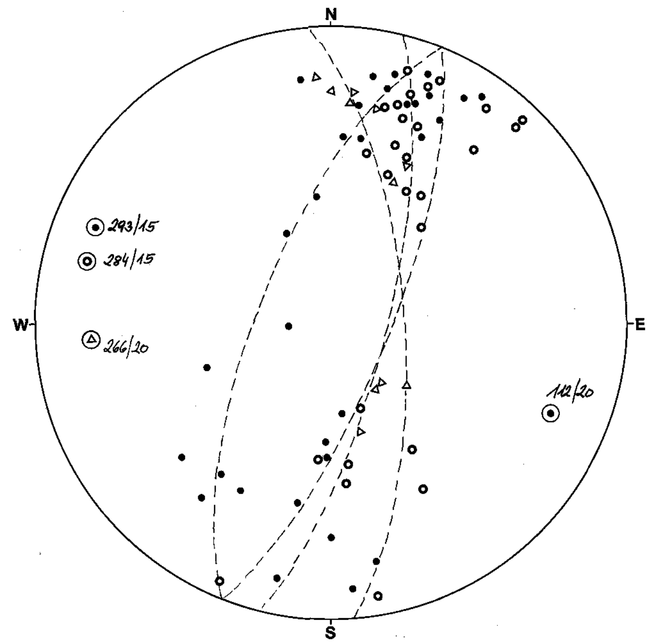


Diagram D_{18}.
Coal-bearing synclines between the tunnels "Nuhi" and "Sina".
Sina Formation, Shale Member and Miankuhi Formation, Coal Bed.
● Western part of the synclinorium (31 poles of bedding planes).
△ Central part of the synclinorium (11 poles of bedding planes).
○ Eastern part of the synclinorium (27 poles of bedding planes).
Schmidt projection.

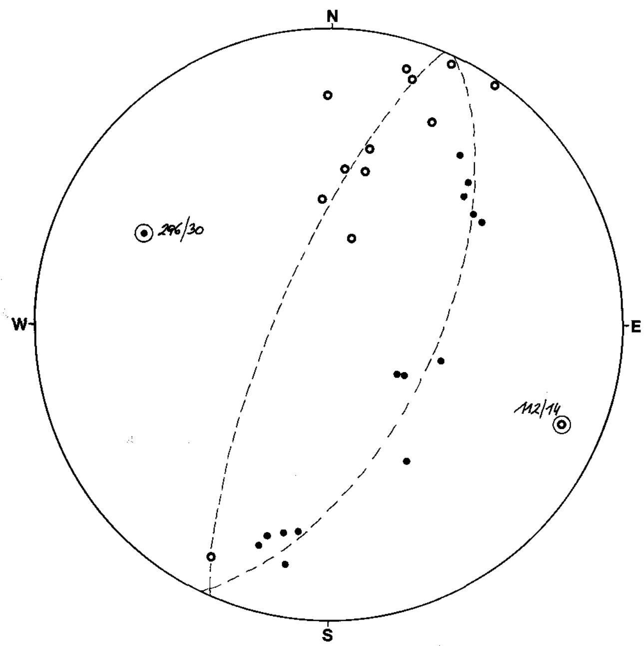


Diagram D_{19}.
Syncline SE Aghdarband settlement.
Tuffaceous sandstone, Sina Formation.
● Eastern part (P. 1088; 14 poles of bedding planes).
○ Western part (P. 1208; 12 poles of bedding planes).
Schmidt projection.

thrust sheet Slice III farther east (cf. cross-sections G–G', H–H', and J–J', Pl. 4). The coal deposit which was mined through Tunnel "Allahverdi", is part of this front anticline (cross-section 4, Pl. 2).

On the whole, the thrust sheet of Slice III becomes wider and increasingly flattens out towards the east; the beds of the Sandstone Member, Sina Formation, are nearly horizontal at the western flank of the Kal-e-Anabeh valley (Fig. 16); they are gently inclined to the south in cross-section K–K' (Pl. 4).

A wedge consisting of Sefid Kuh Limestone and red conglomerate + red sandstone of the Qara Gheitan formation appears south of the "Sina" tunnel at the front of thrust sheet Slice III. The limestone forms an anticline which is well exposed in the cross-cut of Kal-e-Anabeh (Fig. 48). The NW–SE trending axis of this anticline is horizontal; it is in accordance with measurements in Slice II made in the Kal-e-Anabeh valley immediately north of the thrust of Slice III (Diagram D_{22}).

The limestone at the front of thrust sheet Slice III can be followed eastward from there till close to the village Ghal'eh Qabri (see sketch map, Fig. 2); it also shows its anticlinal structure at its eastern end, NW of this village.

A wedge of limestone outcrops at the south-eastern corner of the mapped area directly below (north) of the

Fig. 48.
Anticline of Sefid Kuh Limestone at the front of thrust-sheet Slice III.
Kal-e-Anabeh valley (Diagram 22).

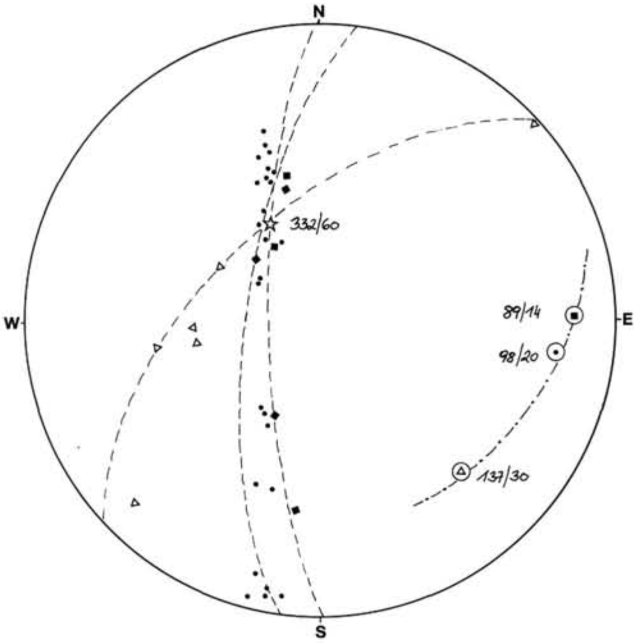


Diagram D_{20}.
Two small anticlines 1 km SSE of the Aghdarband settlement.
Sina Formation.
● SE P. 1061 (26 poles of bedding planes).
■ (5 poles of one and the same bedding plan).
△ 400 farther ESE (6 poles of bedding planes).
* Axis of rotation.
Schmidt projection.

Southern Main Thrust Fault. In front of this limestone-wedge there is an anticline which is composed of the Sandstone Member, Sina Formation, and is marked by the Faqir Bed. The axis of this anticline is gently inclined (10°–20°) towards ESE (cross-section H–H' and Diagram D_{21}).

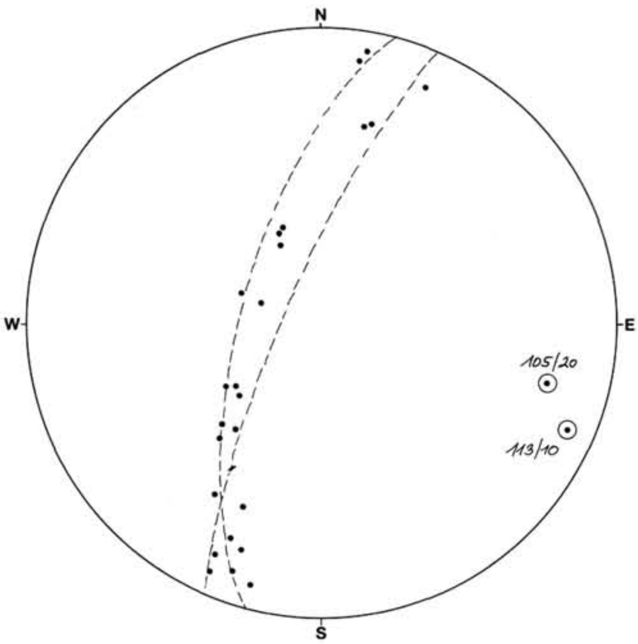


Diagram D_{21}.
Anticlinal fold, west P. 1232.
Sandstone Member, Sina Formation.
● 24 poles of bedding planes.
Schmidt projection.

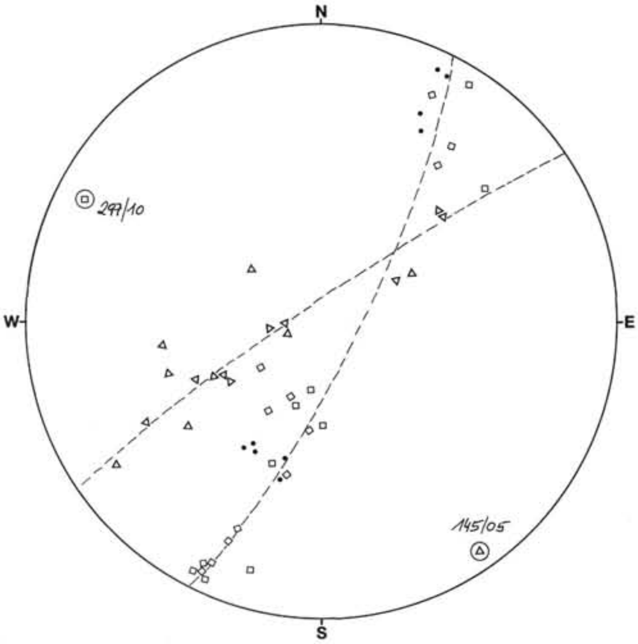


Diagram D_{22}.
Limestone anticline.
Kal-e-Anabeh; see Fig. 48.
Slice III, Sefid Kuh Limestone:
□ Eastern slope of the valley (22 poles of bedding planes).
△ Western slope of the valley (17 poles of bedding planes).
Slice II, immediately N of the thrust fault:
● Sandstone Member of the Sina Formation (9 poles of bedding planes).
Schmidt projection.

7.5. The Southern Main Fault

The Southern Main Fault is a thrust fault: At this fault the schuppenzone of the Southern Frame is thrust from SSW over both structural Slice II (in the western part) and structural Slice III (in the eastern part of the mapped area). Everywhere the fault is accompanied by a crush-zone (cf. Figs. 39b and 49). Not only this crush-zone but also the whole schuppenzone of the Southern Frame (i. e. the Southern Frame proper) and especially its tectonically mixed basal Unit I, seems to be the result of this thrusting.

In the western part of the area, a narrow strip of rocks outcropping immediately north of the Southern Main Fault is characterized by dislodged wedges of Sefid Kuh Limestone and a jumble of rocks of the Sina Formation, especially those of the hard dark-green litharenite. They are dismembered parts of the overturned southern limb of the Aghdarband Syncline (Slice II, Fig. 49). Fragments of the Coal Bed are also exposed at several localities of the southern edge of the Miankuhi Formation.

In the easternmost part of the area, Slice III is intensely folded in front of the Southern Main Fault. Apart from this, there are also indications of the existence of a fourth structural slice in the south-eastern corner of the mapped area. There, a wedge of Sefid Kuh Limestone appears just in front of the Southern Main Fault. Still farther to the east-southeast, outside of the mapped area, a large wedge of rocks forms an anticline, which is inclined to the north – as it is clearly visible from a distance (Fig. 50); it consists of Sefid Kuh Limestone (A. Behroozi, this vol.).

This wedge of Sefid Kuh Limestone seems to form an independent schuppe immediately north of the Southern Main Fault (cf. structural sketch map, Fig. 1). The conspicuously projecting mountain south of this inclined limestone-anticline consists, according to A. Behroozi, of recrystallized limestone, which resembles the "marble" of Early Carboniferous age as exposed along the Northern Main Fault (cf. panorama photo Fig. 50). Both, Sefid Kuh Limestone and recrystallized limestone disappear towards the east, together with the Southern Main Thrust Fault below the veil of Gal'eh Qabri Shales.

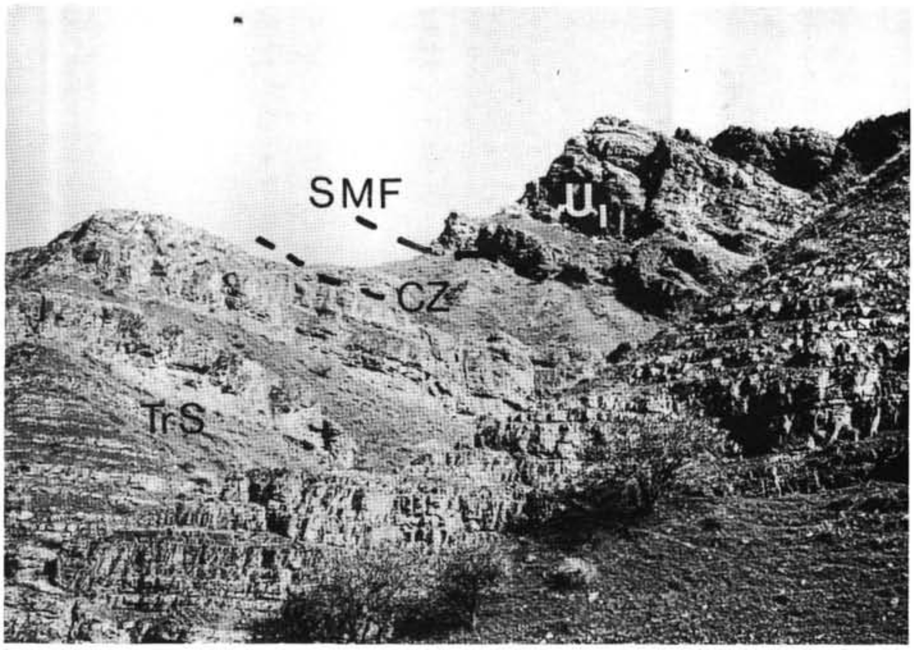


Fig. 49.
Southern Main Fault: Crush-zone, overturned Triassic.
Kal-e-Faqir valley.
TRS = Triassic Sina Formation, sandstone, overturned; CZ = crush zone; SMF = Southern Main Fault; UI = Unit I of the Southern Frame.

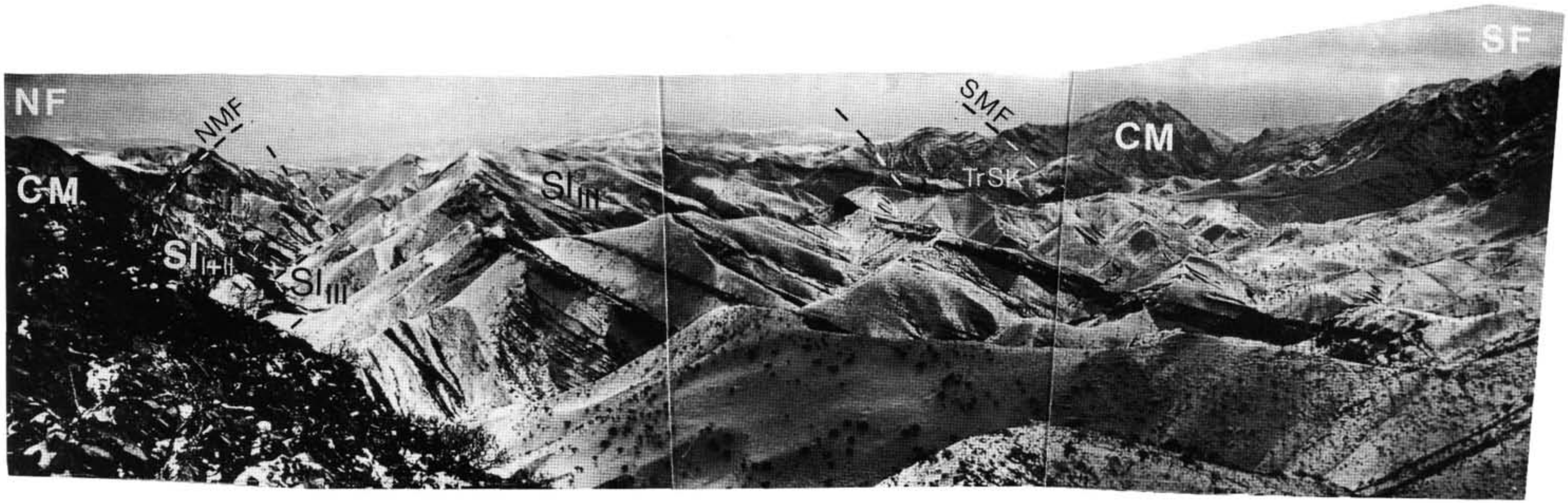


Fig. 50.
Panorama-photo, taken from Kuh-e-Sina (P. 1428, 1 km ENE of the Aghdarband settlement) towards southeast.
CM = Lower Carboniferous limestone of the Northern Frame; NMF = Northern Main Fault; Sl_{I+II} = Slices I and II; Sl_{III} = Slice III; TRSK = Triassic Sefid Kuh Limestone; SMF = Southern Main Fault; SF = Southern Frame; NF = Northern Frame.
Note the frontal lobe of Sefid Kuh limestone below the Southern Main Fault.

8. The Early Cimmerian Kinematics of the Aghdarband Area

The dominant features of the Aghdarband area are three WNW–ESE trending faults, i.e. the Northern Main Fault, the Southern Main Thrust Fault, and – still further to the south and outside the mapped area – the Shahtutak Fault which separates the Southern Frame from the vast area occupied by rocks of the Qara Gheitan formation (see structural sketch map, Fig. 1). The former two of these are relevant to the internal structure of the Triassic, and all three control the present tectonic arrangement, that is: Northern Frame – Triassic of Aghdarband – Southern Frame – southern area consisting of Qara Gheitan formation.

Owing to their plasticity in late Triassic times, the beds of the Aghdarband Group record fairly well the stress which they had to undergo during the Early Cimmerian Orogeny. These deformations disclose some indications of the type of faults which border these beds in the north as well as in the south.

A zone close to the Northern Main Fault – comprising structural Slice I and the northern parts of the structural Slice II – is characterized by the existence of steeply ESE (locally also E and S) plunging fold-axes (cf. Diagrams D_1, D_7, D_8, D_{11}, D_{12}, D_{13}, and Pl. 3).

The fold-axes shown in Diagrams D_7 and D_{11} display varying angles of inclination (10°–64°), but have roughly one and the same direction of plunge (ESE) i.e. all of them occupy roughly the same axial plane. This picture is completed in Diagram D_8 by three gently ESE to SSE plunging axes which seem to be rotated around a rotation-axis, which is steeply (60°) inclined towards the north (see chapter 7.3.1.). A similar picture is displayed in the combined Diagrams D_{12} and D_{13}; there the axis of rotation is inclined (40°) towards the west. The combined Diagrams D_{10} and D_{11} show again a rotation of gently plunging fold-axes from E to ESE plus three ESE plunging (10°, 36°, 54°) fold-axes, which have a common axial plane.

This recurrence of similar arrangements of fold-axes at various locations suggests a compression of the beds from SSW and a shift of the Triassic towards ENE along the Northern Main Fault, showing the latter to be a sinistral side-slip fault.

The vertical fault between structural Slice I and structural Slice II is related to the Northern Main Fault being also a sinistral side-slip fault within the beds of the Aghdarband Group. The wedge-like shape of Slice I, narrowing towards the east, also favours a left lateral separation along these two faults. The only fold measured in structural Sice I ("onion-shaped fold", Diagram D_1) shows three steeply (40°–46°) ENE to ESE plunging axes, which also appear to be rotated around an axis which is inclined (40°) towards the west.

Thrust and compression from SSW is well documented by Diagrams obtained at locations close to the Southern Main Thrust Fault (Diagrams D_5, D_6, D_{20}, D_{21}, and Pl. 3). Apart from this, flatly lying WNW–ESE trending fold-axes prevail in the whole of the eastern part of the area, in structual Slice II (e.g. Diagrams D_{15} and D_{18}) as well as in structural Slice III (Diagram D_{19}). Finally the schuppen structure south of the Southern Main Thrust Fault (i. e. the Southern Frame) points also to a tectonic stress which was active from the south-south-west. This tectonic stress was a main dynamic agent in the Aghdarband area during the Early Cimmerian orogeny.

The Southern Frame and its imbricate structure is cut off to the south by the Shahtutak Fault which separates the slightly metamorphosed rocks of the Southern Frame from the not metamorphosed rocks of the Qara Gheitan formation. This Fault is well discernible on air photos and Landsat images; it is probably the most important fault exposed in the erosional Window of Aghdarband, marking possibly the southern margin of the Turan Plate. A. BEHROOZI, who mapped recently the region south of the Aghdarband area, found along this Fault elongated bodies of limestone (possibly Lower Carboniferous, like the "marble" of the Northern Frame) and – further to the east – also rocks comparable to the Upper Devonian rocks of the Northern Frame. The Shahtutak Fault, also, is probably a side-slip fault, but the direction of displacement along this Fault is not yet known.

Thus, the three controlling faults of the Aghdarband area are: A sinistral side-slip fault in the north and a thrust fault in the south of the Triassic, plus the Shahtutak Fault which is a major fault of unknown character to the south of the Southern Frame. This implies that the regions mentioned above, i.e. Northern Frame, Triassic of Aghdarband, Southern Frame and the area still farther to the south, were not in the same position to each other in the time before the Early Cimmerian orogeny. There was a shift of the Triassic towards ENE with respect to the Northern Frame and a thrust of the Southern Frame over the Triassic. However, we do not know yet where this occurred, since scope and direction of the displacement along the southernmost fault is not at present evident.

All structural elements of the Aghdarband area disappear to the east below the Rhaetian Ghal'eh Qabri Shales, except for the southernmost (Shahtutak Fault). The latter cuts through the Ghal'eh Qabri Shales, indicating that the displacements along this Fault lasted somewhat longer than all other Cimmerian deformations in the Aghdarband area.

9. Late Tertiary – Quaternary

The Jurassic, Cretaceous and early Tertiary history of the Kopet Dagh area is recorded by the cover-beds of the Aghdarband Window. They form regular synclines and anticlines, caused by a mild young-Alpidic (Tertiary) orogeny.

In the Aghdarband area, this Tertiary orogeny resulted in a dome-like uplift, which gave rise to the origin of the erosional window. After the removal of the cover-beds – probably in Late Tertiary times – the landscape was eroded to a peneplain; this mature

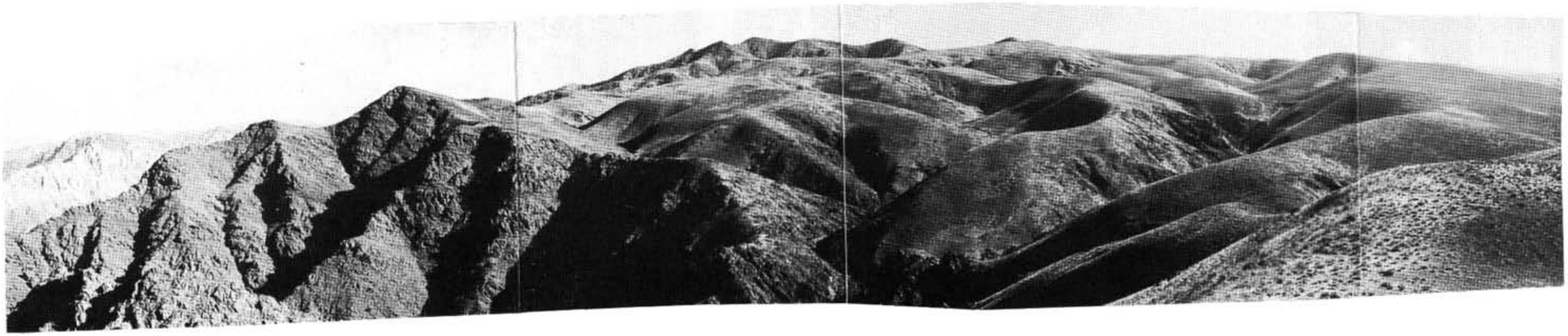


Fig. 51.
Panorama-photo, showing the peneplain-highland of the Southern Frame, south of Aghdarband.

Fig. 52.
Peneplain, Northern Frame.

landscape still exists as a vast plateau at the surface of the Southern Frame, about 400–500 meters above the environments of the Aghdarband village and 600–700 meters higher than the bottom of the Kashaf Rud valley. Small remains of this peneplain are preserved also in the area of the Northern Frame, e. g. in the vicinity of P. 1428 (between cross-sections G–G' and H–H', east of the Aghdarband village) or around P. 1328 (between cross-sections C–C' and D–D', WNW of that village). At the latter location there is exposed a deposit of loose, well rounded gravel mixed with loess (NW P. 1328) which may be related to this old landscape (shown as "loess with boulders" on the geological map, Pl. 1).

This mature landscape is in sharp contrast to the steep, rocky precipices of the southern highland towards the north (Fig. 51) as well as those of the Northern Frame towards both to the south (Triassic of Aghdarband) and to the north (Kashaf Rud valley; Fig. 52). After a long period of tectonic rest (?latest Tertiary – early Quaternary), which resulted in the development of the peneplain mentioned above, the uplift of the Aghdarband area started again, giving rise to an intensified erosional activity by the Kashaf Rud river and its tributaries. This uplift is still going on: the Kashaf Rud cuts deeply in alluvial terraces, which are well developed several meters above the riverbed. These gravel terraces as well as ledges existing at various altitudes at the steep slopes of the southern highlands towards the north, point to an intermittent progress of the uplift.

A peculiar deposit is the l o e s s in the Aghdarband area (Fig. 53). It covers wide areas of the peneplain-highland south of Aghdarband, but also parts of its slopes towards the north and even low-lying aeras east and west of the Aghdarband village. Some boulder-fans, especially those of the south-looking slopes east of the village, are mixed with loess; the boulders acted

Fig. 53.
Loess, covering Triassic rocks.
Aghdarband, view towards west.

apparently as a kind of catch for this wind-born sediment. A layer of boulders is generally the base of the loess-blanket.

Loess sedimentation took place probably during long phases of the Pleistocene. The loess was blown from the vast Turan plain which sweeps north and northeast of the Aghdarband area. Those parts of the area coverd by loess sustain agricultural activities at a modest level because of the water-retaining property of loess and its fertility.

10. Addendum

(R. BRANDNER; received 27. 12. 1990)

Sample No. AG9

(Shown as "Faqir Marl Bed" on the geological map, Plate 1).

- Dark grey, volcaniclastic nodular limestone.
- Wackestones with volcaniclastic detritus, strong bioturbation.
- Crustacean shells with serpulid encrusting.
- Crinoidal stems with borings.
- Baby ammonites, roveacrinoidea.
- Pyritized organic remnants.

Unsoluble residue (det. D. DONOFRIO):

- Radiolarians: *Poulpus priabyx* DE WEVER 1979, found so far in the Upper Triassic only!
- Baby ammonites.
- Pelagic crinoids.
- Holothurians (*Theelia undata* MOSTLER).

Interpretation: Both, the accumulation of crustacean shells and the pyritization point to a poorly ventilated (dysaerobic) bottom milieu; on the other hand, ammonites, pelagic crinoids and radiolarians indicate a pelagic influence.

Sample No. AG10

("Faqir Marl Bed", historical fossil locality No. 33.)

- Red coloured, fossiliferous nodular limestone, strongly bioturbated.
- Wackestone–packstone with thinly shelled pelagic bivalves ("filaments") and pelagic crinoids.

Unsoluble residue:

- Valves of bivalves.

Interpretation: Well ventilated environment, low rate of sedimentation, high accumulation of remains of pelagic organisms; suggestion of a deep-swell facies.

Sample No. AG11

- Alternate bedding of graded packstone (with radiolarians, sponge spicules and "filaments") and tuffaceous sandstones.
- Radiolarians are enriched in individual layers to such a degree (grading according to granulometric qualities) that these layers may be called layers of radiolarite.

Unsolible residue:

- Radiolarians.
- Fish remains.
- Formanifers.

Interpretation: Distal turbiditic gravity flows in the lower slope facies. The microfacies of the sample resembles that of sample No. Agh76/61 (cf. chapter 3.2.3.2., top of the Shale Member, Sina Formation, and D. DONOFRIO, this vol.).

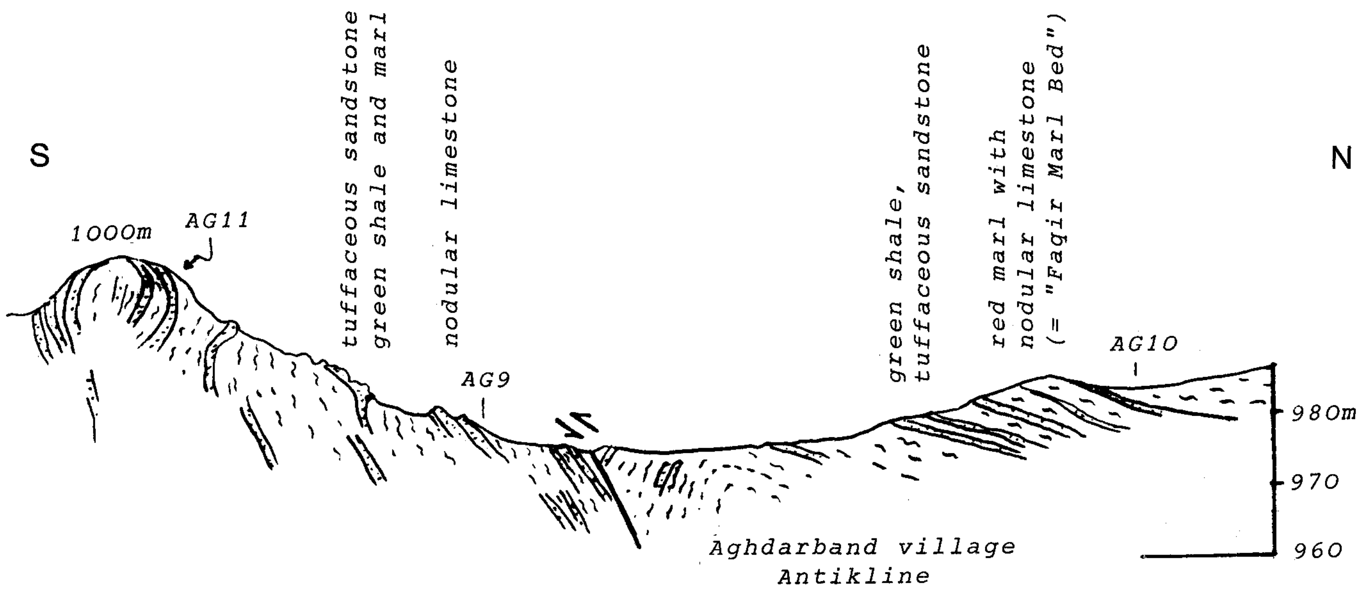


Fig. 54.
Detailed cross-section through the hill P.1000, adjacent to the west of the Aghdarband village (Sina Formation, tuffaceous Shale Member).
- Northern part of the cross-section: Faqir Marl Bed with the historical fossil locality (No. 33), Upper Longobardian. The Aghdarband village anticline is truncated by a sinistral oblique-slip fault.
- Southern part of the cross section: Faqir Marl Bed and top portion of the tuffaceous Shale Member, inverted.

Finds of radiolarians in sample No. AG11 (*Poulpus piabyx* DE WEVER, det. D. DONOFRIO) indicate a Cordevolian age.
Sample No. Agh76/61 (Upper Triassic, cf. D. DONOFRIO, this vol.) is collected ESE of P.1000 in same overturned sequence.

11. Conclusions – Speculations

❶

Despite contrary views of Iranian colleagues, the present writer adhers to the opinion that the Triassic of Aghdarband was deposited on southern marginal parts of the Hercynian Turan Plate. He considers the Upper Devonian and Lower Carboniferous rocks exposed in the Northern Frame of the Triassic to be part of this plate, since they are closely related to coeval rocks of the Caucasian foreland. Similar rocks were found by EFTEKHARNEZHAD & BEHROOZI along the Shahtutak Fault to the south of the Aghdarband area proper. This Fault marks possibly the southern edge of the Turan Plate.

❷

The Early Scythian Qara Gheitan formation is interpreted here to be the upper (Triassic) part of the "Hercynian Molasse". The slightly metamorphosed red and green coloured clastic rocks and slates of the Southern Frame may belong to lower parts of this Molasse. It is assumed that both rest on Hercynian deformed Paleozoic rocks of the Turan Plate in the area situated to the North of the Shahtutak Fault. On the other hand, EFTEKHARNEZHAD & BEHROOZI found a normal transgressive contact of the Qara Gheitan formation with ophiolitic rocks in the very south-west of the window, the latter being most probably Permian in age. This suggests the visualization of a huge talus-fan, which reached from the Hercynian orogenetic belt to the south over the southern continental margin down to an adjacent oceanic trough in Early Triassic times. The sediments of a Permian (?Triassic) ocean floor are exposed 40 kilometers farther to the south in the ophiolitic belt Fariman – Torbat-e-Jam (EFTEKHARNEZHAD & BEHROOZI). Still farther to the south, the Sorkh Shale Formation of Central Iran may have been the far distant equivalent of the Qara Gheitan formation (BRANDNER).

❸

The Triassic "Sea of Aghdarband" – represented by the four formations of the Aghdarband Group – was a northern epicontinental part of the Tethys realm. This is characterized by its intermittent existence and, periodically, by strong Triassic volcanic activity in its vicinity.

❹

The Triassic sequence is interrupted by an ephemeral phase of erosion (probably) in Late Anisian times, and by a stratigraphic gap which comprises the Late Carnian and, probably, also the Early Norian. Thus, three periods of Triassic sedimentation can be distinguished, i.e:

1) Late Scythian – Early Anisian,
2) Ladinian – Early Carnian
   and
3) Late Norian – Early Rhaetian.

A. BAUD differentiates eight "events"; event No. 3 coincides with the end of the first period, event No. 7 roughly with the end of the second period, and event No. 8 with the end of the third period of sedimentation. R. BRANDNER, on the other hand, includes in the first period of sedimentation also the Qara Gheitan formation and considers the combination Qara Gheitan formation + Sefid Kuh limestone Formation + Nazarkardeh Formation to be the upper part of the Hercynian Molasse.

❺

Traces of volcanism are to be found in the Upper Scythian and Lower Anisian. However, the intermediate to acidic volcanism had the climax of its activity in Ladinian times. The volcanism ceased to be active in the Early Carnian. A. BAUD and G. STAMPFLI postulate a back-arc setting of the Ladinian "Sea of Aghdarband"; however, the present writer did not find any indications of a back-arc rifting in the Triassic sequences of Aghdarband.

❻

R. BRANDNER sees in the Late Scythian Sefid Kuh Limestone close relationships to coeval other parts of the Tethys realm and L. KRYSTYN states the pan-Tethyan character of the ammonite fauna of the Late Ladinian Faqir Marl Bed (Fossil Horizon 2), in accordance with E. KRISTAN-TOLLMANNN with respect to the echinoderms and ostracods.

❼

However, the Early Anisian "Nicomedites fauna" of the Nazarkardeh Formation ("Fossil Horizon 1") is restricted, according to L. KRYSTYN,

" ... to a relatively narrow strip which encircles the entire southern edge of Triassic Laurasia from Turkey as far as the Pacific and is designated as the 'North Tethyan Subprovince' ... "

❽

The Anabeh Conglomerate was found as a conspicuous interlayer in the Sandstone Member of the Sina Formation only in structural Slice III. A. BAUD found in limestone components of this conglomerate microfaunas of Middle Carboniferous, Late Permian and Latest Permian age respectively. Of these, the Late Permian microfauna is similar to the Upper Nesen microfacies of the Alborz Mountains; the Latest Permian microfauna seems to have an equivalent in central Afghanistan (SW Kabul). An oldland must therefore have existed south to south-west of the Ladinian sea of Aghdarband which was composed in part of metamorphics, volcanics and limestone of Carboniferous and Permian age, the latter showing relationships particularly with the Alborz Mountains.

❾

Large stems of *Equisetum* sp., enclosed in sandstone and oospores of Characeae, found in a variegated intercalation of shale in the Sandstone Member of the Sina Formation, also indicate that a shore was not far away during the second period of sedimentation. The Ladinian sea became deeper upwards; the Shale Member of the Sina Formation is conceived by A. BAUD to be a deposit of a "distal, deep ramp environment". The quick shallowing and drying up of the sea in Early Carnian time is all the more very remarkable.

⑩

During the third period of sedimentation, the "Sea of Aghdarband" was an isolated marine basin providing extremely bad living conditions for organisms in Norian (?Rhaetian) times (Miankuhi Formation).

⑪

The structure of the Triassic rocks is a combination of compressional folding with side-slip faulting. The folding axes are frequently steeply inclined, being rotated to this high-angle position through side-slip faulting. An analysis of this rotation proves a sinistral shift along the Northern Main Fault. Thrust-faulting and overfolding impart alpinotype features to the tectonic framework. However, we are in the dark as far as the position of individual structural elements of the Aghdarband area to each other in Triassic times is concerned, since scope and – as in the case of the Shahtutak Fault – also direction of the displacement along the three main faults of the area is not known at present.

⑫

The age-span of the Early Cimmerian orogeny can be confined to the time of Late Norian to Early Rhaetian in the Aghdarband area.

⑬

Generally, the results obtained in the Aghdarband area favour a geodynamic model, which puts the Alborz Mountains and Central Iran not very far distantly from the southern margin of the Turan Plate in Triassic times. It seems that this distance was also not very large during the Paleozoic. EFTEKHARNEZHAD's and BEHROOZI's equalization of the Paleozoic rocks of the Northern Frame with those of the Alborz Mountains is not without foundation, and K. WEDDIGE (1984) has impressively documented the influence of the Hercynian orogeny on the Upper Paleozoic of Central Iran. According to this author, a miogeosyncline existed in the north-eastern part of re-rotated Central Iran during the Late Devonian and Early Carboniferous, the features of which

" ... reflect a position of the Iranian sea at the southern margin of the Turan Eugeosyncline ... "

In accordance with this is H.P. SCHÖNLAUB's statement:

" ... The small conodont fauna is assigned to an offshore open marine environment at the continental margin ... "

Thus, the Upper Devonian of Aghdarband may be considered to represent a middle joint between the miogeosyncline of Central Iran (including the Alborz Mountains) and the eugeosyncline of the Turan Plate.

⑭

The "Cimmerian foldbelt" can only be traced in isolated localities through southern Asia (cf. e.g. J. STÖCKLIN, 1983; A.M.C. SENGÖR, 1985; A.A. BELOV et al., 1986; J. BOULIN, 1988), because it is covered by post-Triassic sedimentary sequences over large areas, and/or is deformed by post-Eocimmerian tectonic events. The area of Aghdarband is such a locality; it offers not only undisturbed Eocimmerian structures, but also, to their south in the area Fariman – Torbat-e-Jam, an exposed Permian ocean floor.

⑮

The present writer was fortunate enough to visit the area of Fariman under the guidance of J. EFTEKHARNEZHAD and A. BEHROOZI in June 1988. He was very impressed by exposures of turbidites (siltstone, sandstone and even limestone) and radiolarites, as well as outcrops of serpentinite and spilites, the latter clearly showing pillow features. A sample of red chert collected from this assemblage of oceanic rocks yielded pelagic conodonts which indicate a topmost Kungarian to lower Chihsian (i.e., latest Early Permian) age.

" ... The determinable conodonts are typical representatives of these pelagic Circum-Pacific and Tethyan Permian faunas ... " (KOZUR & MOSTLER, this vol.).

Embedded in the oceanic rock assemblage are blocks and huge bodies of shallow water limestone ("oncolitic sparite") which contain a Lower Permian fauna being somewhat older (Asselian to Sakmarian, and Sakmarian to Murghavian, respectively) than the pelagic conodont fauna mentioned above (F. BOZORGNIA in: EFTEKHARNEZHAD & BEHROOZI, this vol.). These limestone bodies may have been originated from an adjacent shelf area; the Permian ocean appears to have been a rather narrow one!

An upper unit of this ophiolitic belt consisting of sericite schists, phyllites and slates may be of Late Permian to Early Triassic age (EFTEKHARNEZHAD & BEHROOZI).

⑯

It may thus be speculated that part of a Permian ocean floor could have been saved from an assumed Permian subduction, now covered by Jurassic sedimentary rocks in the area to the north of Fariman. The mélange-character of the ophiolites of Darreh Anjir, exposed in the southwestern corner of the Aghdarband Window, could be attributed to an obduction of these ophiolites on to the southern edge of the Turan Plate. This process must have come to an end in latest Permian time because of the transgressive contact of the Early Scythian Qara Gheitan formation with these ophilites.

This view implies that that neither an assumed backarc setting of the Ladinian Aghdarband Sea (A. BAUD) nor the Eocimmerian deformations were directly connected with the Permian closing of the Paleotethys.

⑰

An alternative is that this ocean floor was the result of Permian rifting, preceding the Eocimmerian orogeny. Most results and reflections cited above favour this hypothesis. This is also discussed by H. KOZUR (in: KOZUR & MOSTLER, this vol.) in a broader context.

It should be mentioned that K. WEDDIGE suspected already in 1984 a Permian "basinal facies area" in the area east and west of Mashhad, located to the north of a Permian carbonate platform!

Acknowledgements

I am greatly indebted to

- the Société Minak for providing excellent topographic maps and for the transport of the collected rock-samples to Vienna,
- Eng. H. VASSIGH, then the manager of the coal mine, for his hospitality and help at Aghdarband,
- my companion in the field, JADOLLAH, for his effectiveness in collecting fossils,
- IGCP-Project No. 4 (Upper Triassic of the Tethys Realm) for support to the printing of the coloured geological map (Pl. 1),
- the drafts-team of the Geological Survey of Austria, Vienna, for their excellent work,
- Miss E. KRONSTEINER for producing excellent black-and-white photos from coloured slides,
- my friend J. STÖCKLIN for his advice and for making available his fieldbooks and sections concerning the Aghdarband area,
- my colleagues and friends A. BAUD, R. BRANDNER, M. DAVOUDZADEH, J. EFTEKHARNEZHAD, L. KRYSTYN, and R. OBERHAUSER for many fruitful discussions,

and last not least,

- Dr. John MEYER for his valuable linguistic help.

References

ADAMIA, Sh.A., CHKHOTUA, T., KEKELIA, M., LORDKIPANIDZE, M., SHAVISHVILI, I. & ZAKARIDZE, G. (1981): Tectonics of the Caucasus and adjoining regions: implications for the evolution of the Tethys ocean. – J. Struct. Geol., **3**/4, 437–447.

AFSHAR-HARP, A. (1979): The stratigraphy, tectonics and petroleum geology of the Kopet Dagh region, northern Iran. – Unpubl. Ph. D. Thesis; London University.

ASSERETO, R. (1974): Aegean and Bithynian: Proposal for two new Anisian substages. – In: H. ZAPFE (ed.): The stratigraphy of the Alpine-Mediterranian Triassic, Österr. Akad. Wiss., Schriftenr. Erdwiss. Komm., **2**, 23–39, Wien – New York (Springer).

BAUD, A., BRANDNER, R. & DONOFRIO, D.A. (this vol.): The Sefid Kuh Limestone – a late Lower Triassic carbonate ramp (Aghdarband, NE–Iran). – Abh. Geol. B.-A., **38**, Wien.

BAUD, A., STAMPFLI, G. & STEEN, D. (with contributions of R. CAS and H. SARP (this vol.): The Triassic Aghdarband Group: volcanism and geological evolution. – Abh. Geol. B.-A., **38**, Wien.

BAUD, A. & STAMPFLI, G. (1989): Tectonogenesis and evolution of a segment of the Cimmerides: The volcano-sedimentary Triassic of Aghdarband (Kopet Dagh, North-East Iran). – In: A.M.D. SENGÖR (ed.): Tectonic Evolution of the Tethyan Region, 265–275 (Kluwer Academic Publishers).

BELOV, A.A., SOMIN, M.L. & ADAMYIA, Sh.A. (1978): Precambrian and Paleozoic of the Caucasus (Brief Synthesis). – Jahrb. Geol. B.-A., **121**, 155–175, Wien.

BELOV, A.A., GATINSKY, Y.G. & MOSSAKOVSKY, A.A. (1986): A precis on pre-Alpine Tectonic History of Tethyan Paleoceans. – Tectonophysics, **127**, 197–211, Amsterdam – Oxford – New York – Tokyo (Elsevier).

BOERSMA, M. & VAN KONIJNENBURG-VAN CITTERT, J.H.A. (this vol.): Late Triassic plant megafossils from the Triassic of Aghdarband, eastern Iran. – Abh. Geol. B.-A., **38**, Wien.

BOULIN, J. (1988): Hercynian and Eocimmerian events in Afghanistan and adjoining regions. – Tectonophysics, **148**, 253–278, Amsterdam – Oxford – New York – Tokyo (Elsevier).

BOZORGNIA, F. (1973): Paleozoic foraminiferal biostratigraphy of Central and East Alborz Mountains, Iran. – National Iranian Oil Company, Geological Laboratories, Publication No. 4, Tehran.

BREZHNEV, V.D., GORIANOV, V.B. KLISHEVITCH, L.V., MARTYSHEV, V.R., NASYBULIN, N.N. & ZUBTSOV, E.I. (1967): Devonian of Tien Shan. – Intern. Symposium on the Devonian System, Calgary, Alberta, Alberta Soc. Petrol. Geol., Vol. **1**, 433–450.

DAVOUDZADEH, M. & SCHMIDT, K. (1981): Contribution to the Paleogeography of the Upper Triassic to Middle Jurassic of Iran. – N. Jb. Geol. Paläont. Abh., **162**/2, 137–163, Stuttgart (Schweizerbart).

DAVOUDZADEH, M. & SCHMIDT, K. (1982): Zur Trias des Iran. – Geol. Rundsch., **71**/3, 1021–1039, Stuttgart (Enke).

DAVOUDZADEH, M. & SCHMIDT, K. (1984): A review of the Mesozoic Paleogeography and Paleotectonic Evolution of Iran. – N. Jb. Geol. Paläont. Abh., **168**, 182–207, Stuttgart (Schweizerbart).

DAVOUDZADEH, M., SOFFEL, H. & SCHMIDT, K. (1981): On the rotation of Central-East-Iran microplate. – N. Jb. Geol. Paläont. Mh., **1981**/3, 180–192, Stuttgart (Schweizerbart).

DAVOUDZADEH, M. & WEBER-DIEFENBACH, K. (1987): Contribution to the Paleogeography and Tectonics of the Upper-Paleozoic of Iran. – N. Jb. Geol. Paläont. Abh., **175/**2, 121–146, Stuttgart (Schweizerbart).

DONOFRIO, D.A. (this vol.): Radiolaria and Porifera (-spicula) from the Upper Triassic of Aghdarband (NE-Iran). – Abh. Geol. B.-A., **38**, Wien.

EFTEKHARNEZHAD, J. & BEHROOZI, A. (this vol.): Geodynamic significance of recent discoveries of Ophiolites and Late Paleozoic rocks in NE-Iran (including Kopet Dagh). – Abh. Geol. B.-A., **38**, Wien.

GOLDSCHMID, K.T. (1956): Report on the coal deposit of Aghdarband. – Iranian Oil Comp. (unpublished), Tehran.

HAMDI, B. & JANVIER, Ph. (1981): Some Conodonts and Fish Remains from Lower Devonian (lower part of the Khoshyeylaq Formation) North-East Shahrud, Iran. – Geological Survey of Iran Report No. **49**, Tehran.

KRISTAN-TOLLMANN, E. (this vol.): Echinoderms from the Middle Triassic Sina Formation (Aghdarband Group) in NE-Iran. – Abh. Geol. B.-A., **38** Wien.

KRISTAN-TOLLMANN, E. (this vol.): Ostracods from the Middle Triassic Sina Formation (Aghdarband Group) in NE-Iran. – Abh. Geol. B.-A., **38**, Wien.

KRYSTYN, L. & TATZREITER, F.(this vol.): Middle Triassic Ammonoids from Aghdarband (Iran) and their paleobiogeographical significance. – Abh. Geol. B.-A., **38**, Wien.

KURCHAVOV, A.M. (1985): Zonation of Devonian orogenic volcanism in Kazakhstan and Central Asia (in Russian). – Geotectonics, No. **6**, Moscow.

MADANI, M. (1977): A study of the sedimentology, stratigraphy and regional geology of the Jurassic rocks of Eastern Kopet Dagh, NE-Iran. – Unpublished Ph. D. Thesis, London University.

OBERHAUSER, R. (1960): Foraminiferen und Mikrofossilien „incertae sedis" der ladinischen und karnischen Stufe der Trias aus den Ostalpen und aus Persien. – Jb. Geol. B.-A., Sbd. **5**, 5–46, Wien.

OBERHAUSER, R. (this vol.): Triassic Foraminifera from the Aghdarband Group (Faqir Bed of the Sina Formation), NE-Iran. – Abh. Geol. B.-A., **38**, Wien.

RUTTNER, A.W. (1977): The Coal Deposit of Aghdarband (NE-Iran). – Société Minak (unpublished report), Tehran.

RUTTNER, A.W. (1980): Sedimentation und Gebirgsbildung in Ost-Iran, erläutert an drei Beispielen. – Berliner geowiss. Abh., **20**, (Festschrift Max Richter), 3–20, Berlin.

RUTTNER, A.W. (1983): The pre-Liassic basement of the Aq Darband area, eastern Kopet Dagh Range. – Geological Survey of Iran Report No. **51**, Tehran.

RUTTNER, A.W. (1984): The pre-Liassic basement of the eastern Kopet Dagh Range. – N. Jb. Geol. Paläont. Abh., **168**, 256–268, Suttgart (Schweizerbart).

RUTTNER, A.W. (1988): The coal deposits of Aghdarband (Aqdarband) NE-Iran and its geological frame. – Second Mining Symposium Iran (Kerman), Ministry of Mines and Metals, 183–202, Tehran.

SCHÖNLAUB, H.P. (this vol.): Condonts from the Variscan basement of the Eastern Kopet Dagh Range (Northern Iran). – Abh. Geol. B.-A., **38**, Wien.

SENGÖR, A.M.C. (1985): Die Alpiden und die Kimmeriden: Die verdoppelte Geschichte der Tethys. – Geol. Rdsch., **74**/2, 181–313, Stuttgart (Schweizerbart).

SENGÖR, A.M.C. (1990): A new model for the Paleozoic – Mesozoic evolution of Iran and implications for Oman. – In.: A.H.F. ROBERTSON, M. SEARLE & A.C. RIES (eds.): The Geology and Tectonics of the Oman Region. – Geological Society Publication No. **49**, 797–831, London.

SEYED-EMAMI, K. (1971): A summary of the Triassic in Iran. – Geological Survey of Iran, Report No. **20**, 41–53, Tehran.

SIBLÍK, M. (this vol.): Triassic Brachiopods from Aghdarband (NE-Iran). – Abh. Geol. B.-A., **38**, Wien.

STÖCKLIN, J. (1977): Structural correlation of the Alpine ranges between Iran and Central Asia. – Mém. h. sér. Soc. Géol. France, **8**, 333–353, Paris.

STÖCKLIN, J. (1980): Geology of Nepal and its regional frame. – J. geol. Soc. London, **137**, 1–34, London.

STÖCKLIN, J. (1983): Himalayan Orogeny and Earth Expansion. – In: CAREY, S.W. (ed.): Expanding Earth Symposium, Sydney 1981, 119–130, University of Tasmania.

STÖCKLIN, J. (1984): Orogeny and Tethys Evolution in the Middle East – an appraisal of current concepts. – 27th Intern. geol. congress Moscow.

TIKHY, N.Y. (1967): Main features of the Devonian history of U.S.S.R. Intern. Symposium on the Devonian System, Calgary, Alberta; Alberta Soc. Petrol Geol., vol. **1**, 349–358.

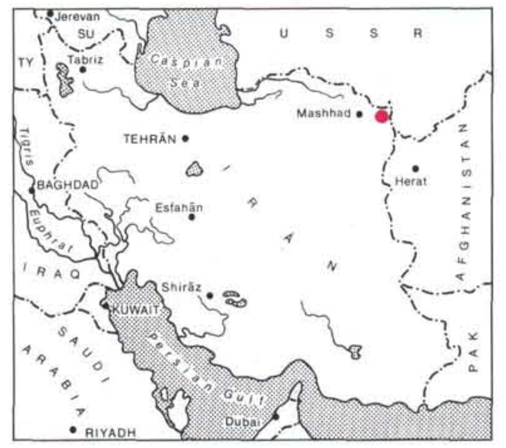
WEDDIGE, K. (1984): Externally controlled Late Paleozoic Events of the Iran Plate. – N. Jb. geol. Paläont. Abh., **168**, 278–286, Stuttgart (Schweizerbart).

Geological Map of the Aghdarband-Area (NE-Iran)

Mapped by A. RUTTNER 1975–1977

Scale 1 : 12.500

Location of the Area



Index

1	Alluvium i.g.
2	Alluvial fan
3	Talus of rock debris and boulders
4	Terrace
5	Loess
6	Loess with boulders

Triassic
Aghdarband Formation

Member 4	7	Shale, non marine, brownish
	8	Sandstone (hanging wall of the Coal Horizon)
	9	Coal Horizon
Member 3	10	Shale, marine, dark greenish-grey, tuffaceous
	11	"Tufflava", dark green; pillows
	12	Tuffaceous sandstone, partly "Tufflava" (between shale)
	13	Conglomerate; whitish sandstone (between shale)
Member 2	14	*Fossil-Horizon 2*: shale light green and purple, rich in fossils; *Late Ladinian*
	15	Tuff and tuffaceous sandstone, greenish-grey
	16	"Tufflava", dark green
	17	Conglomerate, containing white quartz pebbles
Member 1	18	Transition beds: tuffaceous sandstone and limestone alternating
	19	*Fossil-Horizon 1* in transition beds; *Early Anisian*
	20	Conglomerate, consisting of limestone pebbles
	21	Limestone
	22	Crushed limestone

Permo-Triassic

23	Sandstone, conglomerate and shale, brownish-red or greenish
24	Basic volcanic rocks

Pre-Triassic
Northern Frame of the Triassic

Upper Devonian	25	Slate, reddish-brown
	26	Limestone, dark grey to black; shale, black; diabase: *Upper Devonian*
	27	Sandstone and breccia, dark green, hard; conglomerate
	28	Slate, light green; with layers of limestone: *Upper Devonian*
	29	Marble
	30	Dykes of diabase

Southern Frame of the Triassic

Unit I	31	Crush-zone
	32	Shale and sandstone, brownish-red or violet-red, partly green
	33	Sandstone, compact, violet-red
	34	Conglomerate, brownish-red (*?Permo-Triassic*)
Unit II	35	Sandstone and shale, grey, with plant remains
	36	Sandstone, violet-red or green; conglomerate
Unit III	37	Slate, green, sericitic
Unit IV	38	Sandstone, greenish-grey
Unit V	39	Slate, violet, sericitic
	40	Sandstone, violet; conglomerate

Thrust

Fault

Dip of bedding

0–5° – 30° – 60° – 85° – 90°

Plunge of folding-axes

0–5° – 15° – 30° – 55° – 85°

Tunnel (coal mine)

Mega- / Micro- fossil-locality

4 — *Structural section*

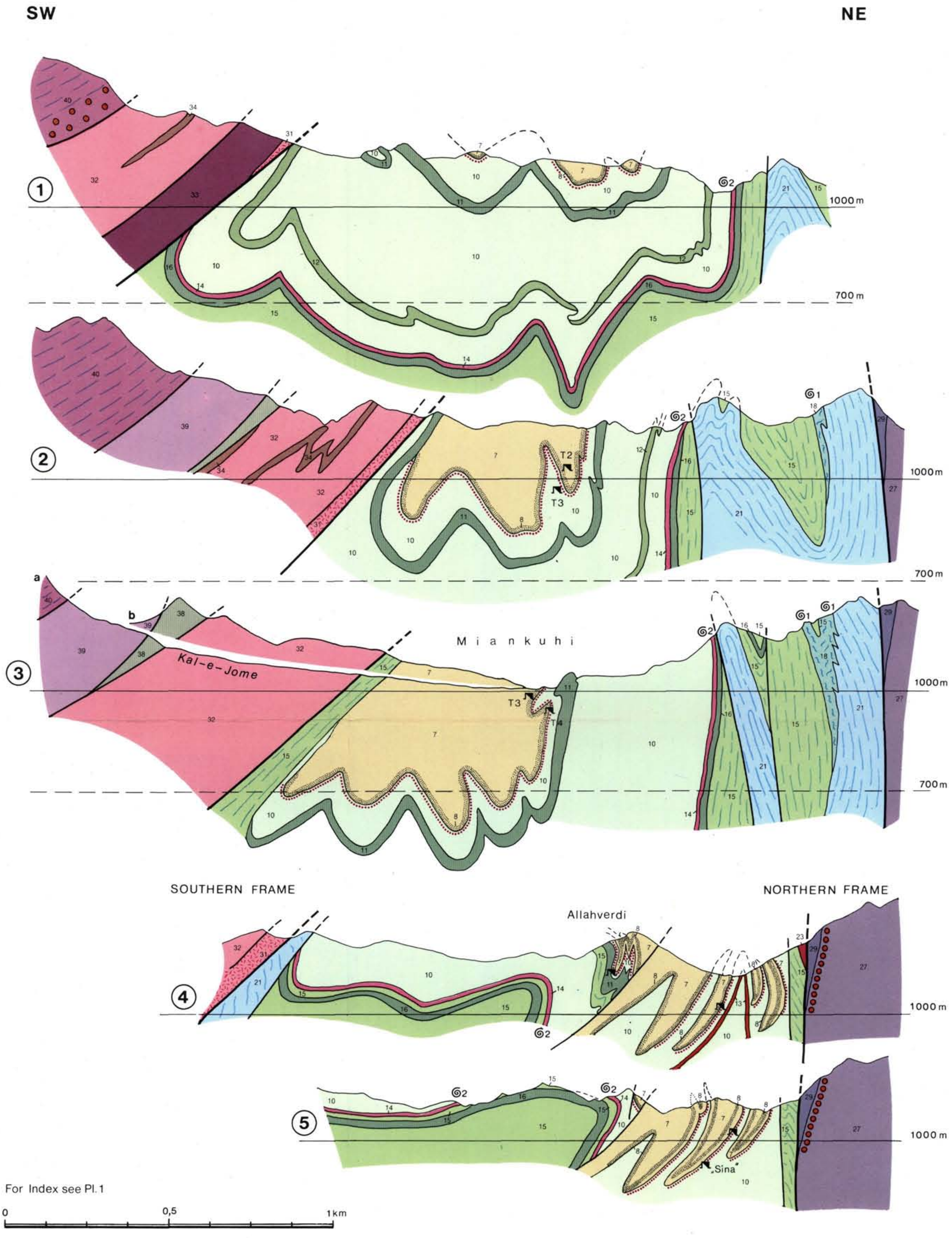
△858 Elevation in meters

2 ···· Stratigraphic section

Layout: M. Ledolter. Graphic realization: E. Freiberger, A. Gottschald, M. Ledolter. Reproduction technique: S. Laschenko.
The printing of this map was supported by the IGCP-Project No. 73/I/4 "Triassic of the Tethys Realm".

Printed by Technische Universität Wien,
Institut für Kartographie und Reproduktionstechnik.

Aghdarband Sections 1 – 5



For Index see Pl. 1

Geological Map of the Aghdarband-Area (NE-Iran) (Only Contour Map)

Scale 1 : 12.500

1 Alluvium i.g.

2 Alluvial fan

3 Talus of rock debris and boulders

4 Terrace

5 Loess

6 Loess with boulders

Triassic
Aghdarband Group

Miankuhi Formation

7 Shale, brownish

8 Sandstone (hanging wall of the Coal Horizon)

9 Coal Horizon

Sina Formation – Shale Member

10 Shale, dark greenish-grey, tuffaceous

11 Volcanic "litharenite", dark green; pillows?

12 Tuffaceous sandstone (between shale)

13 Conglomerate; whitish sandstone (between shale)

14 Faqir Marl Bed (*Fossil Horizon 2*) shale and marl, light green and purple, rich in fossils; *Late Ladinian*

Sina Volcanic Formation – Sandstone Member

15 Tuffaceous sandstone, greenish-grey; tuffaceous shale and marl (interbedded)

16 Volcanic "litharenite", dark green

17 Anabeh Conglomerate, containing white quartz pebbles

20 Conglomerate, consisting of limestone pebbles

Nazarkardeh Formation

18 Tuffaceous shale and limestone alternating

19 *Fossil Horizon 1, Early Anisian*

Sefid Kuh Limestone Formation

21 Limestone

22 Crushed limestone

Qara Gheitan Formation

23 Sandstone, conglomerate and shale, brownish-red or green; *Early Scythian*

24 Basic volcanic rocks

Pre-Triassic
Northern Frame of the Triassic

Upper Devonian

25 Slate, reddish-brown

26 Limestone, dark grey to black; shale, black; tuffite; *Late Devonian*

27 Volcaniclastic sandstone and breccia, dark green, hard; conglomerate

28 Slate, light green; with layers of limestone; *Late Devonian*

29 "Marble"; *Early Carboniferous*

30 Dykes of diabase

Southern Frame of the Triassic

Unit I

31 Crush zone

32 Shale and sandstone, brownish-red or violet-red, partly green

33 Sandstone, compact, violet-red

34 Conglomerate, brownish-red (Qara Gheitan Formation)

35 Sandstone and shale, grey, with plant remains; *Triassic*

Unit II

36 Sandstone, violet-red or green; conglomerate

Unit III

37 Slate, green, sericitic

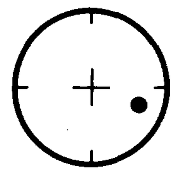
Unit IV

38 Sandstone, greenish-grey

39 Slate, violet, sericitic

Unit V

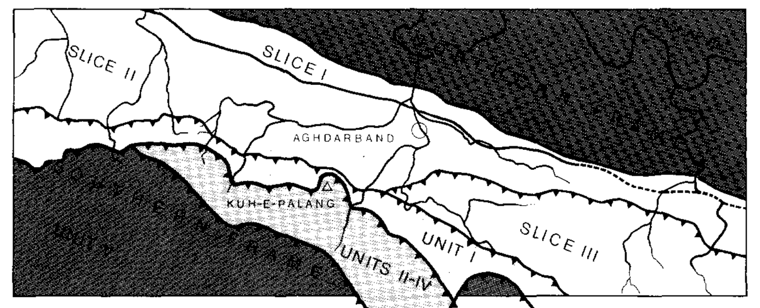
40 Sandstone, violet, conglomerate



Measured fold axes (Schmidt Projection)

The numbers refer to the diagrams, chapter 6

H — H' Position of structural cross-sections (Plate 4)



Aghdarband Sections (1988, A - K)

Graphik: G. Ullsperger

Zeitschrift/Journal: Abhandlungen der Geologischen Bundesanstalt in Wien

Jahr/Year: 1991

Band/Volume: 38

Autor(en)/Author(s): Ruttner Anton Wolfgang

Artikel/Article: Geology of the Aghdarband Area (Kopet Dagh, NE-Iran) 7-79