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30 August - 2 September 2023
University of Lausanne, Switzerland

Edited by Aymon Baud

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Page de couverture: l'auteur dans le géosite de l'Arche près de Ras al Hadd en Oman
Cover photograph: the Oman Arch Geosite near Ras al Hadd, with the author

ACROSS THE END PERMIAN “GREAT EXTINCTION”: FROM FIELD STUDIES TO SCIENTIFIC RESULTS

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EDITOR’S FOREWORD

The Conference « Across the End Permian “Great Extinction”: from Permian-Triassic Field Studies to Scientific Results » is to look back, celebrate, and pay tribute to Dr. Aymon Baud, fifty years of continuous Permian-Triassic field research and corresponding publications produced in part with the support of the Swiss National Science Foundation (SNSF), the Geological Museum of Lausanne and in association with the University of Lausanne, Switzerland. General scientific themes are organized in six plenary sessions over three days, starting August 30, 2023, with keynote talks and regular lectures, that will take place in the Auditorium 1216 of the Synathlon building on the campus of the University of Lausanne.

The Lausanne Organizing Committee comprise Profs Allison Daley, Michel Jaboyedoff, Jean-Luc Epard, TorstenVennenann, Thierry Adatte. Dr Aymon Baud is coordinator.

The Scientific Committee comprise the Profs Benoit Beauchamp (University of Calgary), Charles Henderson (University of Calgary), Hugo Bucher (University of Zurich), Nicolas Goudemand (ENS Lyon) and Sara Pruss (Smith College, Northampton, MA).

Contents

Cinquante-cinq ans de recherches sur les périodes Permien-Trias, travaux de cartographie, de levers de terrain avec les publications correspondantes par Aymon Baud, en collaboration avec l'Institut de Géologie de l'Université de Lausanne, Suisse, 1968-2013

Aymon Baud

Chercheur associé, Institut des Sciences de la Terre, Faculté des Géosciences de l'Université de Lausanne, Suisse.

Ce texte illustré a été préparé pour la conférence «Across the End Permian "Great Extinction": from Permian-Triassic Field Studies to Scientific Results» qui s'est tenue du 30 août au 2septembre 2023 à l'Université de Lausanne, en Suisse. Ce sont cinquante-cinq années de recherches faites sur le terrain avec l'analyse des couches déposées durant le Permien-Trias et les publications correspondantes. Celles-ci ont été produites avec l'aide de nombreux collègues et de différents organismes dont le Fonds national suisse de la Recherche scientifique (FNSRS), l'Académie suisse des sciences naturelles, le service des Activités culturelles de l'Etat de Vaud, ceci en association avec le personnel de l'Institut et du musée de Géologie de l'Université de Lausanne, en Suisse. Nous y présentons 5 périodes, chacune subdivisée en 8 à 12 chapitres.

1 – La première période : 1968-1984

Cette première période concerne 17 années d'études doctorales et de publications, d'une collaboration très fructueuse avec des collègues et des professeurs, de recherches faites sur le terrain et en laboratoire, finalisée par la présentation d'un travail de doctorat.

1.1 – Études doctorales sur la succession des carbonates du Trias moyen des Préalpes aux Alpes occidentales, 1968-1984.

Le 22 avril 1968, j'ai obtenu ma maîtrise en géologie et le professeur Héli Badoux (Fig. 1a), directeur de l'Institut de Géologie m'a proposé un poste d'assistant à l'Université et un sujet de thèse sur la sédimentologie et la stratigraphie de la succession carbonatée du Trias moyen de la partie interne du domaine des Préalpes suisses. Pour débuter, il y a eu l'étude des carrières de Saint-Triphon dans la vallée du Rhône, ceci à la suite du professeur de Géologie François Ellenberger (Fig. 1b), de la Sorbonne, Paris qui a été le premier à corréler la succession triasique des Préalpes suisses dont Saint-Triphon avec la succession triasique de la partie interne des Alpes occidentales dénommée «domaine Briançonnais».

J'ai d'abord contacté le Dr Francis Hirsch (Fig. 1c), paléontologue de l'Université de Zurich : nous avons relevé et échantillonné les calcaires à silex de l'Anisien, où il a trouvé des conodontes par dissolution. Cela a conduit à ma première publication en tant que co-auteur (Baud et al., 1968).

Figure 1 : Portraits, a) professeur Héli Badoux ; b) professeur François Ellenberger ; c) Dr Francis Hirsch.

Après 4 ans comme assistant à l'Institut de Géologie, j'ai été invité à être assistant au musée de Géologie de Lausanne en 1972 puis, en 1974, j'ai été nommé conservateur de ce musée.

Cette année-là, j'ai alors collaboré avec le Dr Henri Masson et, après une reconnaissance sur le terrain, nous avons découvert (Fig. 2) le vertébré fossile apparemment le plus ancien de Suisse (Baud, 1975).

Grande « première » géologique

FOSSILES DES PLUS VIEUX VERTÉBRÉS DE SUISSE DÉCOUVERTS PRÈS D'AIGLE

Fin de l'ère primaire, début de l'ère secondaire. L'Europe est un grand désert. Et puis, ce sont, très lentes, les grandes invasions marines. Il n'y a encore ni mammifères, ni oiseaux. Juste quelques dinosaures, d'autres reptiles et des poissons.

220 millions d'années c'est l'âge de quelques fossiles retrouvés par deux jeunes géologues lausannois sur la colline appelée « Le Petit Plantour », entre Aigle et Ollon. Ces restes préhistoriques affleuraient à une paroi rocheuse qui domine les vignes de la commune d'Ollon, « Les Noches ».

Comment expliquer la présence de ces fossiles à cet endroit ?

Il y a 50 millions d'années s'amorçait un grand bouleversement, un déplacement des continents vers le nord. L'Afrique — au ralenti — entre en « collision » avec l'Europe, qui se plisse, se tord et fait se retourner les masses rocheuses, pour donner naissance à nos montagnes. La paroi où a été effectuée la découverte se serait trouvée à plusieurs milliers de mètres de profondeur, si ce grand chambardement ne s'était produit.

La chance

Leur domaine de « recherche fondamentale » est différent, mais leurs intérêts se rejoignent souvent. C'est ensemble que MM. Aymon Baud, conservateur du musée de géologie, et Henri Masson, premier assistant de l'Institut de géologie de l'Université, ont eu la chance fantastique — au mois de mai de cette année — de réaliser une « première ». Ce n'est toutefois pas le fruit du simple hasard. M. Baud étudiait cette région, pour sa thèse, depuis plusieurs années. Du travail précis, scientifique.

La découverte, intéressante à plus d'un titre est excessivement importante puisque les deux fossiles sont les plus anciens restes de vertébrés trouvés en Suisse jusqu'à ce jour. Ils ont été analysés par le Dr de Beaumont, de Genève.

De quoi s'agit-il ?

D'une dent de poisson du genre Saurichthys mesurant quelque 5 mm. de long et d'une côte de reptile du genre Nothosaurus, mesurant 3 cm. de long. On sait que ce reptile était une sorte de gros lézard d'une longueur de 40 cm. environ.

Les deux géologues lausannois, MM. Aymon Baud (à droite) et M. Henri Masson. — (Photos tlm - J.-P. Grisel)

Le « cas » les lingules

Outre cela, les deux géologues ont encore ramené de leur « expédition » au « Petit Plantour » des algues fossilisées, des lys de mer, des blocs de pierre laissant apparaître des traces de cheminement de crabes, ainsi que des lingules. Les lingules ressemblent à de petits mollusques — des vers vivant dans une coquille organisée à la manière de celle de l'huitre — : fait à relever, ces animaux n'ont absolument pas évolué depuis plus de 220 millions d'années. Il s'agit là d'un cas presque unique et partiellement inexpliqué.

Les restes fossilisés de vertébrés — la dent et la côte — sont caractéristiques de la faune des pays chauds. Il ne faut pas oublier qu'à cette époque, l'Europe était plus proche de la zone tropicale que de nos jours.

Et, à l'aube de l'hiver, l'on se prend à rêver à ce que pouvait être la température de la Suisse il y a quelque 200 millions d'années...

C. Ds

Une dent de reptile d'il y a 220 millions d'années.

Figure 2 : Extrait du journal Le Matin du 5.9.1974.

Les articles suivants portent sur les Crustacés décapodes (Baud, 1976) et mon point de vue sur l'échelle stratigraphique du Trias (Baud, 1977).

Sur la limite Permien-Trias, une première collaboration avec mes collègues Demir Altiner, Jean Guex et Gérard Stampfli débouche sur des corrélations dans quelques localités du Moyen-Orient et la mise en évidence de stromatolites à la base du Trias (Altiner et al., 1980). Cette mise en évidence sera reprise au chap. 3.8.

Pour l'étude des argiles contenues dans les carbonates triasiques, j'ai entamé une collaboration avec le professeur Bernard Kubler de l'Université de Neuchâtel, et son cours sur la minéralogie de l'argile a beaucoup aidé à l'étude de la teneur en argile dans les calcaires anisiens et, avec celle de la cristallinité de l'illite, nous avons pu déterminer les zones d'anchi-métamorphisme du Trias des Préalpes (Baud, 1984).

Jusqu'en 1983, j'ai poursuivi de nombreuses collaborations, relatées ci-après, qui m'ont permis de participer à la publication de 22 articles et de rédiger les 300 pages de mon manuscrit de thèse (Baud, 1984, 1987), tout en poursuivant, durant certains étés, la cartographie géologique du Trias sur les cartes Les Mosses, (Lombard et al., 1975), Niesen, Adelboden (Furrer et al., 1993) et Zweissimen de l'atlas géologique suisse au 1 :25'000ème.

En décembre 1984, j'ai soutenu mon travail de thèse avec une annexe de ces 22 articles publiés sur « L'histoire naturelle du calcaire de Saint-Triphon (Anisien, Trias moyen, Préalpes suisses) », et j'ai obtenu les félicitations du jury.

1.2 – Collaboration avec le professeur Paul Brönimann de l'Université de Genève et son assistante Dr Louisette Zaninetti

En cartographiant, et échantillonnant de nombreux affleurements anisiens dans les Préalpes, j'ai effectué l'étude des lames minces, ce qui m'a permis de découvrir d'abondants foraminifères, des microfossiles encore jamais décrits dans les couches anisiennes de ces régions. Ce fut le début d'une collaboration fructueuse avec le professeur Paul Brönimann de l'Université de Genève et son assistante de thèse Louisette Zaninetti, spécialisée dans les foraminifères triasiques. Les résultats ont abouti à la publication de six articles paléontologiques (foraminifères et coprolithes) sur les calcaires anisiens des Préalpes de 1971 à 1974 (Baud et al., 1971, 1972, 1974 ; Broennimann et al., 1972 ; Zaninetti et al., 1972a, b).

1.3 – Travaux de terrain hors d'Europe, début de l'étude du Permien en Iran et au Pakistan, 1972-1975

J'ai eu la chance de poursuivre une coopération étroite avec Paul Brönimann et Louisette Zaninetti, qui m'ont invité à effectuer des recherches sur les couches du Permien et du Trias de l'Iran en octobre 1972 (Fig. 3) et en octobre 1974 (Baud et al., 1972, 1974). En mars 1975, le Permien-Trias des Salt et des Trans-Indus Ranges du Pakistan ont été l'objet de nos recherches sur le terrain, avec des sections stratigraphiques clés, dont les nombreux échantillons et les lames minces ont d'abord été stockées à l'Institut paléontologique de Genève, puis données au musée de Géologie de Lausanne ou j'en ai pris soin.

1.4 – Collaboration avec le Dr Joséphine Mégard-Galli, assistante du Prof. Ellenberger de Paris-Sorbonne

Une autre coopération fructueuse commence en 1972 avec J. Mégard-Galli, et nous étudions ensemble une partie des meilleurs affleurements triasiques des Alpes occidentales du Briançonnais, ainsi que les carbonates du Trias moyen de Corse et de Sardaigne. Cela a permis d'établir des corrélations extrêmement précises entre la nouvelle formation de Saint-Triphon et les unités qui l'entourent, d'âge Trias inférieur et moyen, depuis la Suisse centrale jusqu'à la Méditerranée, en passant par les Alpes occidentales.

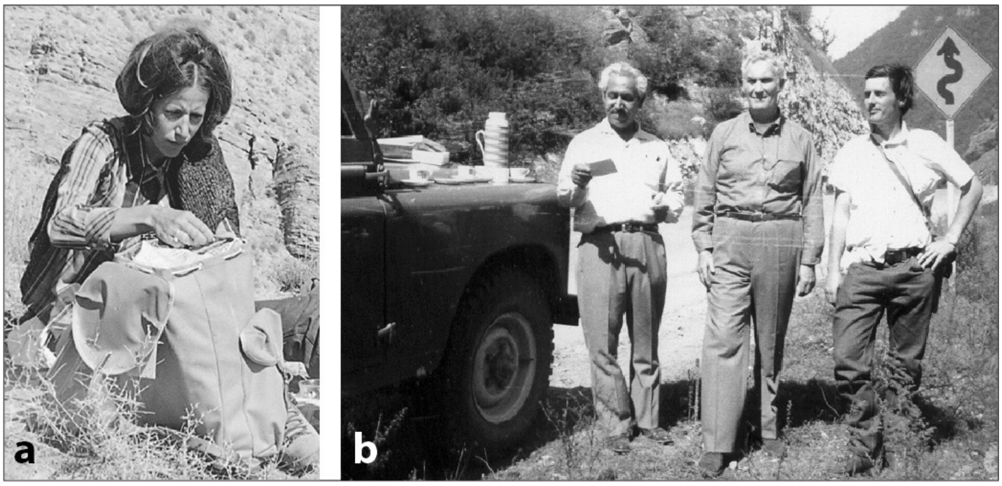

Figure 3 : Travaux de terrain en Iran, a) Dr. Zaninettiprend des notes ; b) Dr. Bozorgnia, Prof. Brönimann, et l'auteur lors de la traversée de l'Elbourz.

Plusieurs présentations dans des congrès internationaux et de nombreuses publications permettent de détailler ces corrélations et de présenter de nouvelles méthodes basées sur la cyclicité de la sédimentation carbonatée et sur les grandes séquences transgressives-régressives nouvellement découvertes (Baud & Mégard-Galli, 1975, 1977 ; Mégard-Galli & Baud, 1977). C'est avec elle que de grandes avancées ont été réalisées dans la stratigraphie et la sédimentologie du Trias briançonnais, et c'est elle qui a été à l'origine d'une synthèse sur le Trias des Alpes occidentales publiée dans les Mémoires du BRGM en 1994 (Mégard-Galli et al. 1984).

1.5 – Etudes de terrain Himalaya-Ladakh, d'abord avec l'Institut de Géologie de Lausanne, suivies d'une coopération avec des collègues de Grenoble et de Milan, de 1977 à 1983

En janvier 1979, j'ai rassemblé un groupe de recherche lausannois sur l'Himalaya. Avec les Professeurs A. Escher, H. Masson et A. Steck, j'ai co-organisé la première géotraversée du Zanskar oriental Hemis-Padum en 1979 (Fig. 4) et les résultats ont été publiés dans Baud et al. (1982, 1983).

En 1981, avec le Prof. G. Mascle (Grenoble) et le Dr E. Garzanti (Milan), nous avons organisé une expédition pour réaliser des coupes stratigraphiques détaillées et des observations tectoniques dans le Zanskar central, au N et à l'E de la Klippe ophiolitique de Spongtang (Baud et al., 1985 ; Garzanti et al, 1987).

En 1983, invité par le professeur M. Gaetani (Milan), j'ai participé à une géotraversée SE-NW de Darcha (Lahul) à Thongde (Zanskar) en passant par Sarchu, Phirtse- La et Phugtal (Baud et al., 1984).

Les principaux résultats obtenus en collaboration avec les équipes mentionnées ci-dessus peuvent être résumés comme suit :

1. La découverte et la définition d'une structure de nappes superposées à grande échelle des unités sédimentaires du Zanskar (Tethys Himalaya). Malgré de fortes oppositions et controverses sur la théorie des nappes de la part de géologues autochtonistes, la structure des nappes a été récemment largement confirmée par des travaux de terrain et de cartographie détaillés.
2. Le profil géologique à travers le Zanskar oriental, de Hemis à Padum.
3. Des coupes stratigraphiques détaillées des sédiments de la fin du Crétacé et du début du Tertiaire du Zanskar central avec l'interprétation géodynamique de l'enregistrement sédimentaire de l'avancée de l'Inde vers le nord.

La suite de cette coopération est décrite dans le chapitre 2.9.

L'aventureux devoir de vacances des géologues de l'Université de Lausanne

UNE EXPÉDITION AU LADAKH

Dans les milieux non universitaires, on fait souvent aux étudiants une réputation de dilettantes privilégiés, oisifs une bonne partie de l'année pendant de longues vacances. C'est bien sûr faux, et voici un exemple du contraire : cette année, treize enseignants et étudiants diplômés de l'Institut de géologie et de paléontologie de l'Université de Lausanne ont profité de la pause estivale pour préparer et réaliser (grâce à l'argent d'une fondation et à leurs propres ressources) une expédition scientifique au Ladakh, district le plus septentrionnal de l'Inde. Ils allaient ausculter l'Himalaya, là où des géologues n'avaient jamais passé avant eux. Les trois derniers membres de l'expédition viennent de rentrer à Lausanne, chargés de cailloux asiatiques ; ils nous ont raconté leur aventure

Coincé entre la chaîne himalayenne occidentale et celle du Karakorum, le Ladakh est un paradis, longtemps convoité, des géologues. Partagé aujourd'hui entre le Pakistan

équipé pour la circonstance d'un moteur de tracteur. Ils ont retrouvé à Srinagar, presque à l'heure dite, les autres membres de l'expédition qui avaient pris l'avion. Puis, tout le monde s'est rendu par la route à Leh, capitale du Ladakh. Là, ils ont engagé huit porteurs, loué dix-sept mulets, et ils ont marché vers le sud, quinze jours durant, dans l'Himalaya, franchissant des cols à quatre ou cinq mille mètres, entre des sommets qui culminaient à six mille cinq cents, s'arrêtant pour établir des relevés géologiques, observant les couches et les plis de la montagne, emportant avec eux des pierres.

L'Himalaya et les Alpes

Mais qu'allaient donc chercher — au prix de l'amaigrissement (ils ont tous perdu six ou huit kilos) et de la dysenterie — les géologues lausannois si loin de nos Alpes ? « Il s'agissait d'abord, dit le professeur Arthur Escher, qui dirigeait l'expédition, d'explorer

Devant le Palais de Rumine, le retour des trois derniers membres (fleuris) de l'expédition.

Figure 4 : compte-rendu de notre expédition au Ladakh dans la Feuille d'Avis de Lausanne du 24 octobre 1979.

1.6 – Les conférences internationales suivies de 1971 à 1985 vont être une formation continue en géologie et en stratigraphie

Pour me tenir informé des dernières avancées en matière de sédimentologie et de stratigraphie, j'ai décidé et eu la possibilité de participer à des congrès internationaux. En 1971, après avoir suivi le 8ème Congrès international de sédimentologie à Heidelberg, j'ai participé à une excursion sur le Trias dans les Alpes calcaires septentrionales de Bavière (Dachstein, Hallstatt, Hauptdolomit, lits de Kössen) qui m'a donné une bonne formation sur la stratigraphie du Trias et les recherches en cours en dehors des Alpes occidentales.

J'ai participé au 9ème Congrès international de sédimentologie à Nice en 1975 où nous avons présenté deux communications avec J. Mégard-Galli. Au 11ème Congrès international de sédimentologie à Hamilton en 1982, j'ai donné une courte conférence (Baud, 1982) puis, j'ai rendu visite à E.T. Tozer à Ottawa.

En août 1984, j'ai eu l'occasion de participer au 27e Congrès géologique international (CGI) à Moscou et à la réunion statutaire de la Sous-commission de stratigraphie du Trias (SST) où j'ai été élu vice-président. Ce congrès a été précédé d'une excursion unique sur la limite Permien-Trias dans les montagnes de Verkoyansk en Sibérie orientale le long de la rivière Setorym, et a été suivi d'une excursion en Arménie avec les sections permo-triasiques de Vedi et Sovetachen (Fig. 5b). C'était une occasion exceptionnelle pour les participants de collecter des échantillons dans ces sections éloignées ce qui a permis d'enrichir les collections du musée pour les recherches futures et que nous décrivons dans les chapitres 2.4, 5.7, 5.8 et 5.10.

1.7 – Examen de nouvelles coupes géologiques et échantillonnage effectués dans le cadre des projets triasiques du Programme international de corrélation géologique (PICG) de l'UNESCO

Ma participation aux projets 4 et 106 du PICG a débuté par le Congrès organisé par Isabella Premoli Silva et Maurizio Gaetani en mémoire de R. Assereto et J. Pisa, dans le célèbre château de Bergame (Italie) en1979, où j'ai fait un exposé. En 1980, le projet 4 (Trias) du PICG a été le cadre d'une réunion de terrain à Bratislava (Slovaquie) avec une excursion dans la partie orientale du pays. En 1981, une réunion de terrain à Sarajevo a été organisée par les projets 4 et 106 du PICG et une réunion finale à Vienne (1982).

En mars 1984, j'ai eu l'occasion de participer au premier projet 203 du PICG organisé par un Comité chinois dirigé par le professeur Zun-Yi Yang de Pékin, sur les événements permo-triasiques dans la Téthys orientale. Le projet a débuté par une conférence à Pékin, suivie d'une excursion à la section de Shangsi, dans la province du Sichuan (fig. 5a). La suite de cette participation au projet du PICG est au chapitre 2.2.

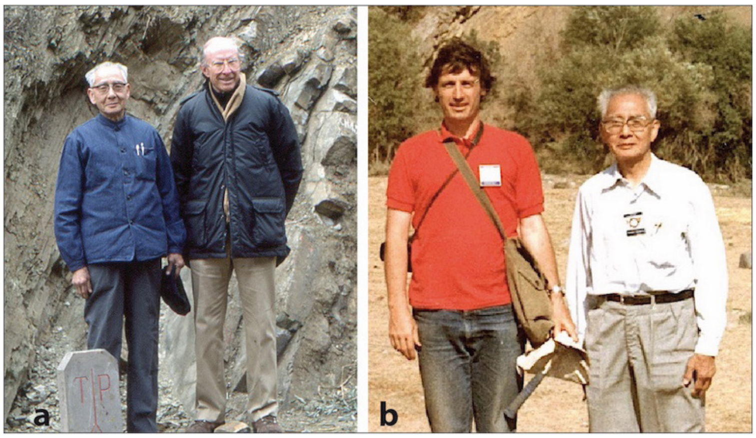

Figure 5 : Le professeur Zun-Yi Yang de Pékin en 1984 : a) Avec Norman Newell sur la limite Permien-Trias de la section de Shangsi en Chine, b) Avec l'auteur devant la section de Sovetachen (Zangakatun) en Arménie.

1.8 – Collaboration nouvelle avec le professeur Dimitri Papanikolaou de l'Université d'Athènes

À l'invitation du professeur Dimitri Papanikolaou de l›Université d'Athènes, j'ai entamé des recherches en Grèce en 1980 et 1981, en découvrant et échantillonnant de nouvelles sections permiennes-triasiques sur les îles de Salamine, Hydra, Chios et Égine, ainsi que sur le Permien de l'Attique, en Grèce orientale (Baud & Papanikolaou, 1981). Nos résultats ont été présentés lors de deux réunions, comme indiqué ci-dessous. La coopération avec lui en Grèce et avec de nouvelles équipes de recherche s'est poursuivie au cours des périodes suivantes.

2 – La deuxième période : 1985-1992

La deuxième période, de 1985 à 1992, raconte une nouvelle histoire car je me suis lancé dans quatre programmes de recherche et j'ai poursuivi avec plusieurs équipes une collaboration sur l'étude du Permien-Trias et de nouvelles lignes de recherche sont apparues.

Au cours de l'année 1985, j'ai assuré l'intérim de Marc Weidmann, directeur du musée de Géologie, qui avait pris un congé sabbatique et j'ai enseigné par intérim durant 2 semestres le cours de sédimentologie des carbonates à l'Institut de Géologie. Puis en 1986, à la suite de sa démission, j'ai été promu directeur du musée de Géologie de Lausanne.

2.1 – La première géotraversée du Tibet occidental en 1985

En 1985, j'ai pris un congé sabbatique pour participer à la première expédition autorisée au Tibet occidental. Cette région de hauts plateaux et de vallées profondes, qui avait toujours été fermée aux Occidentaux, m'a donné l'occasion de découvrir une géotraversée unique du Haut Himalaya jusqu'à la chaîne du Kun Lun, et d'y faire des observations géologiques avant de rejoindre les plaines d'Asie centrale le long de la Route de la Soie. Invité au retour par le professeur Celâl Şengör, j'ai fait un exposé (Baud,1985) à la Conférence d'Istanbul et j'ai publié mes observations dans la région de Kailas (Fig. 6) et le long de la géotraversée Sutlej-Yarkand, dans deux articles (Baud, 1989a ; Baud et al., 1994).

Figure 6 : Le Mont Kailas vu du lac Mansarovar dans l'ouest du Tibet, 1985.

2.2 – Participation aux projets 199 et 203 du Programme International de Corrélation Géologique (PICG) de l'UNESCO

Ma participation au projet PICG s'est poursuivie par des congrès de terrain à Istanbul et Antalya (Turquie, 1986), à Pékin et Nankin (Chine, 1987), dans les Salt Ranges (Pakistan, 1987), ainsi qu'une étude au Cachemire (Inde) et enfin une conférence à Vladivostok (Russie orientale, 1992).

C'est dans le contexte du projet 203 sur le Permien-Trias, qu'en 1986, j'ai co-organisé avec Jean Marcoux et Celâl Shengör une réunion de la sous-commission de stratigraphie du Trias (SST) à Istanbul en Turquie, puis une excursion sur le Trias inférieur de la région, suivie d'une excursion dans les nappes d'Antalya, à l'ouest de Kemer (sud-ouest de la Turquie), avec J. Marcoux et L. Krystyn (Marcoux et al., 1986; Marcoux & Baud, 1988).

En 1987, j'ai participé activement à deux congrès de terrain du projet 199 du PICG sur les événements rares en géologie:

- Le premier a été organisé en mars par Sun Shu de l'Academia Sinica, avec des réunions à Pékin et Nankin et la possibilité de collecter des échantillons dans le stratotype du Changhxingien dans la région de Meishan, dans l'argile de la limite P/Tr et dans les niveaux1 à 3 du Trias le plus précoce (Boclet et al., 1988).
- Le second, organisé par Bilal Haq en décembre 1987, s'est tenu dans les Salt Ranges (Pakistan) e pour échantillonner la section historique de Nammal Gorge. J'y ai participé avec mon étudiante post-doctorante C. Jenny et j'ai collecté des échantillons de la fin du Permien et du début du Trias. Les professeurs M. Gaetani, J. Marcoux et E.T. Tozer y ont également participé. Avec eux, nous avons décidé de nous rendre au Cachemire (Inde) pour effectuer des recherches dans la célèbre section Permien-Trias de Guryul Ravine et pour prendre des échantillons en vue d'une étude ultérieure (Fig. 7), telle que montrée dans les chap. 3.4, 5.4 et 5.10.

Figure 7: Retour du terrain, l'auteur à gauche, avec Jean Marcoux, Tim Tozer et Maurizio Gaetani à Srinagar, Cachemire, Inde le 15 décembre 1987.

Succédant au projet 203 du PICG, le projet 272 « Événements bio-géologiques circumpacifiques du Paléozoïque supérieur et du Mésozoïque inférieur » a été dirigé par J.M. Dickins. Avec lui, en septembre

1992, nous avons aidé Y. Zakharov et G. Kotlyar à organiser la première conférence Permien-Trias avec excursion sur le terrain à Vladivostok (Russie). Elle était parrainée par ce projet 272 du PICG et soutenue par la SST. En tant que co-organisateur, nous avons eu l'occasion, avec les participants, de visiter quatre coupes principales du Permien- Trias de cette région de l'Extrême-Orient russe, enfin ouverte aux scientifiques étrangers. Une collection d'articles a été publiée (Baud et al., editors, 1997) et des corrélations faites (Zakharov et al., 2005). La suite est donnée au chapitre 4.6.

2.3 – Mise en route d'études micropaléontologiques de la Téthys permienne

Ayant la possibilité de proposer des projets de recherche sur les études micropaléontologiques de la Téthys permienne au Fonds national suisse pour la recherche scientifique (FNRS), j'ai reçu une réponse positive et dès 1987, j'ai obtenu le financement d'un poste d'assistante post-doctorale pour le Dr Catherine Jenny, spécialiste des études sur les foraminifères permiens. Avec elle, à l'invitation du professeur Dimitri Papanikolaou de l'Université d'Athènes, nous avons commencé des études sur le Permien en Grèce entre 1987 et 1989. Nous avons effectué des travaux de terrain sur le Permien des îles de Chios, d'Égine et de nouvelles sections sur l'île d'Hydra et avons publié quatre articles (Baud et al., 1990, 1991 ; Baud & Jenny, 1991 ; Jenny-Deshusses & Baud, 1989). En 1990, nous avons collaboré avec K. Grant et M. Nestell pour publier un article sur l'étude du Permien d'Hydra (Grant et al., 1991) et plus tard elle publie une première synthèse sur Hydra (Jenny et al., 2004) qu'elle étend ensuite à toute la Tethys (Jenny et al., 2009).

2.4 – À partir de 1986 commence une nouvelle ligne de recherche : la stratigraphie isotopique du Carbone en collaboration avec les professeurs William Holser (Eugen, USA) et Mordekai Magaritz (Rehovot, Israël)

J'ai entamé une collaboration avec les professeurs William Holser (Eugen, États-Unis) et Mordekai Magaritz (Rehovot, Israël) et j'ai envoyé au laboratoire d'isotopes du Carbone de Magaritz des échantillons de sections clés de la limite Permien-Trias entre les Alpes du Sud et la Chine du Sud que j'avais étudiés et dont j'avais inscrit toutes les informations au musée de Géologie de Lausanne. Nous avons ainsi pu constituer une nouvelle base de données sur les isotopes stables du Carbone et préparer des communications pour les prochaines réunions sur le Permien-Trias ainsi qu'un article clé sur la stratigraphie isotopique du Carbone sur le passage du Permien au Trias (Baud et al., 1986 ; Baud & Magaritz, 1988, 1989 ; Magaritz et al. 1988).

Stimulés par le projet PICG 199, avec de nouvelles possibilités d'échantillonnage sur des successions permiennes et triasiques clés, nous avons publié, après analyse, douze sections bien datées avec une courbe isotopique du Carbone à partir d'échantillons de carbonate marin étudiés et classés, montrant en 1989, pour la première fois, le changement global enregistré à la limite entre les deux périodes : un nouvel outil pour la corrélation de cette limite Permien-Trias marin a été créé. Deux coupes de référence mondiale située en Chine, celles de Meishan et de Shangsi, étaient concernées et illustrées (Baud et al., 1989).

Les résultats ont dépassé nos attentes et, après une première publication dans le périodique « Nature », cet article écrit en 1989 a eu un impact considérable et un indice de citation élevé.

2.5 – De vice-président à la présidence de la sous-commission de stratigraphie du Trias (SST)

Après avoir été vice-président en 1984, j'ai été élu nouveau président de celle-ci, élection confirmée par la Commission internationale de stratigraphie lors du Congrès géologique international (CGI) qui s'est tenu en 1989 à Washington, D.C. J'y ai donné une conférence (Baud, 1989b) et eu la possibilité de participer à l'excursion sur le terrain dans le Texas occidental et d'y prendre connaissance des couches du Permien que je viendrai étudier avec J. Marcoux par la suite (Chapitre 2.7). J'y ai retrouvé le professeur Norman Newell du musée d'histoire naturelle de New York avec qui j'avais participé à la première excursion géologique en Chine.

Ma tâche de président m'a amené à proposer un congrès sur le Trias et à promouvoir l'accord sur les noms et les limites des étages. À la demande des membres de la sous-commission, j'ai constitué en 1991 un comité d'organisation d'un symposium sur la stratigraphie du Trias à Lausanne. En octobre 1991, Jean Guex (Lausanne), Maurizio Gaetani (Milan), Jean Marcoux (Paris) et Hans Rieber (Zurich) m'ont aidé à diriger ce symposium avec la contribution du personnel du musée, de l'Institut de Géologie et de l'Université de Lausanne.

Ce symposium a réuni une cinquantaine d'experts de 22 pays pendant quatre jours (Baud, ed. 1991), suivis d'une excursion locale d'une journée dans les carrières anisiennes de Saint-Triphon (Fig. 8) et dans la mine de sel norienne de Bex (Baud & Meisser, 1991). Avec la sous-commission, nous avons décidé, suite à des votes positifs, de proposer deux étages pour le Trias inférieur : l'Induen et l'Olenekien. Tous ensemble, nous avons participé au comité éditorial du compte-rendu du Symposium (Guex & Baud, 1994). La fin de cette présidence est présentée au chapitre 3.6.

Figure 8 : De gauche à droite, nos collègues W. Weitchat, A. Dagis, H. Rieber et Y. Zacharov à l'excursion de Saint-Triphon en 1991.

2.6 – Participation à des congrès géologiques internationaux et à des voyages d'étude sur le terrain

En 1991, j'ai eu l'occasion de participer au congrès international sur le Permien dans sa localité type, soit à Perm en Russie. J'ai fait un exposé sur la succession permienne en Grèce et participé à l'excursion sur les couches du Permien de l'Oural. C'était l'occasion de rencontrer à nouveau, après le CIG de 1984 à Moscou, les collègues russes, soit les professeurs Galina Kotlyar de St-Petersbourg et Yuri Zakharov de Vladivostok et de préparer avec eux pour 1992, une réunion internationale de terrain sur le Permien et le Trias à Vladivostok mentionnée au chapitre 2.1.

En août 1992, en tant que président de la SST, j'ai participé au congrès géologique international de Kyoto (IGC). Au symposium en l'honneur du professeur Augusto Gansser, j'ai fait un exposé sur l'ouverture de la Néotethys en Oman (Baud, 1992). Puis j'ai participé à une excursion post-congrès sur les couches permiennes dans le centre du Japon, puis rejoint notre réunion de Vladivostok (voir pages 7-8).

2.7 – Participation de 1989 à 1992 au programme de recherche international «Tethys» avec des travaux sur le terrain en Oman, dans l'île de Timor et au Texas occidental.

L'année 1989 marque le début de mon implication dans un important programme de recherche international appelé «Groupement Scientifique Tethys» qui nous a soutenus financièrement et le début de recherches géologiques en Oman dans l'île de Timor et dans le Texas occidental. Avec le professeur Jean Marcoux et l'assistante post-doctorale Sylvie Crasquin, nous avons mis en place des groupes de travail sur le Permien et le Trias. Plusieurs réunions de travail ont eu lieu en 1989 et 1990, respectivement au musée de Géologie de Lausanne et à Paris.

Dans le cadre de ce programme de recherche international «Tethys», des échantillons permiens et triasiques ont été collectés entre 1989 et 1992 en Oman (Baud et al., 1989), et en 1991 dans les calcaires rouges à ammonoïdes de l'île de Timor (Fig. 9b) en Indonésie (Baud & Marcoux, 1991).

Pour compléter nos données, nous avons organisé avec Jean Marcoux des recherches sur le terrain dans le Bassin Permien de l'ouest du Texas (Baud & Marcoux, 1989).

Avec Gérard Stampfli, nouveau professeur de géodynamique nommé à Lausanne, nous avons repris l'histoire des marges téthysiennes pour en publier, sous sa direction, une synthèse (Stampfli et al., 1991). Nous avons aussi repris des travaux sur des échantillons de l'Iran oriental reçus de notre collègue autrichien Anton Ruttner (Baud, Brandner et al., 1991, Baud, Stampfli et al., 1991).

Jean Marcoux a supervisé le groupe de travail sur les cartes paléogéographiques et paléo-environnementales du Trias (cartes de l'Anisien et du Norien) et m'a beaucoup aidé pour établir la carte du Permien moyen, le Murgabien (Baud et al., 1993).

Les résultats et les cartes paléogéographiques des programmes de recherche internationaux «Tethys» ont été présentés lors d'une réunion finale en 1992. Les trois cartes et les notes d'accompagnement sur les environnements permiens et triasiques produites par notre groupe de recherche; (Marcoux et al., 1993a, 1993b) font partie d'un grand livre imprimé fin 1992 (Fig. 9a), sous la direction de Dercourt et al., 1993, et nous avons publié les paléoenvironnements du Permien et du Trias dans un livre de synthèse (Marcoux & Baud, 1996).

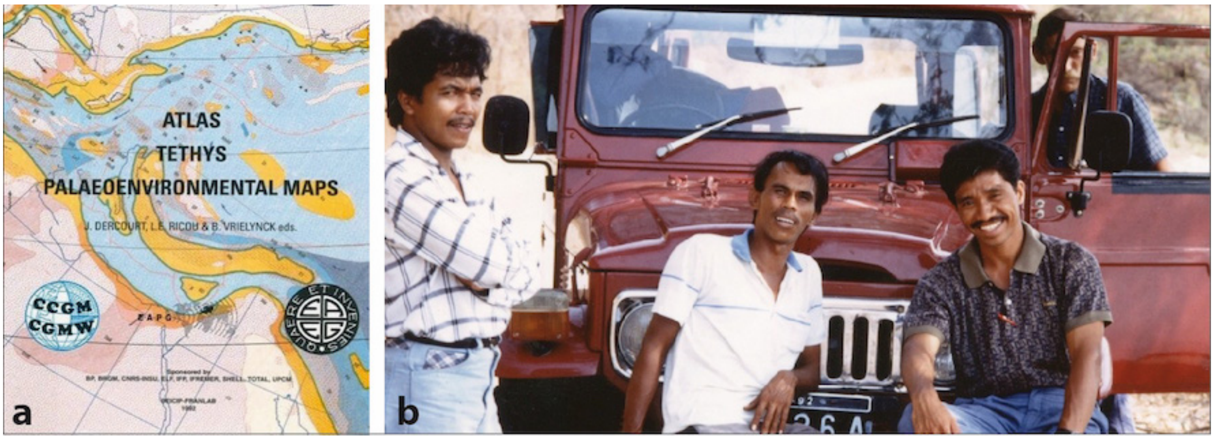

Figure 9 : a) couverture de l'Atlas Tethys, b) Nos guides indonésiens sur l'île de Timor et Jean Marcoux à l'arrière à droite, au cours de nos travaux de terrain.

2.8 – Invitation du Prof. Benoit Beauchamp à entreprendre des travaux de terrain dans les stratotypes du Trias inférieur du Haut-Arctique canadien, en juillet 1992

Lors de la conférence de Perm en 1991, j'ai rencontré pour la première fois le Dr Benoit Beauchamp du Service géologique du Canada à Calgary (Canada), qui m'a proposé deux objectifs :
a. participation au projet Pangea,
b. participation à des recherches de terrain sur le Permien-Trias dans le Haut-Arctique canadien avec le soutien de la Commission géologique du Canada.

J'ai accepté ces propositions avec enthousiasme et c'est à la fin du mois de juin 1992 que j'ai pu rejoindre sur l'île d'Ellesmere l'expédition de terrain de Benoît Beauchamp dans le Haut-Arctique canadien. Des profils des sections types du Permien tardif et Trias précoce de l'Arctique ont été étudiés et des échantillons de roches de la transition Permien-Trias ont été envoyés au musée de Géologie de Lausanne pour analyse.

2.9 – Participation au groupe de recherche Himalaya avec les professeurs Henri Masson, Gérard Stampfli et Albrecht Steck

Avec notre groupe de recherche de l'Université de Lausanne sur l'Himalaya, composé des professeurs H. Masson, G. Stampfli et A. Steck, nous avons proposé d'organiser à Lausanne en 1988 le quatrième symposium Himalaya-Karakoram-Tibet, ainsi qu'une exposition publique sur nos travaux géologiques et nos découvertes dans l'Himalaya du Ladakh (Fig. 10).

J'ai rédigé les actes de la conférence (Baud, 1989c) et une réponse à G. Fuchs (Baud 1989d).

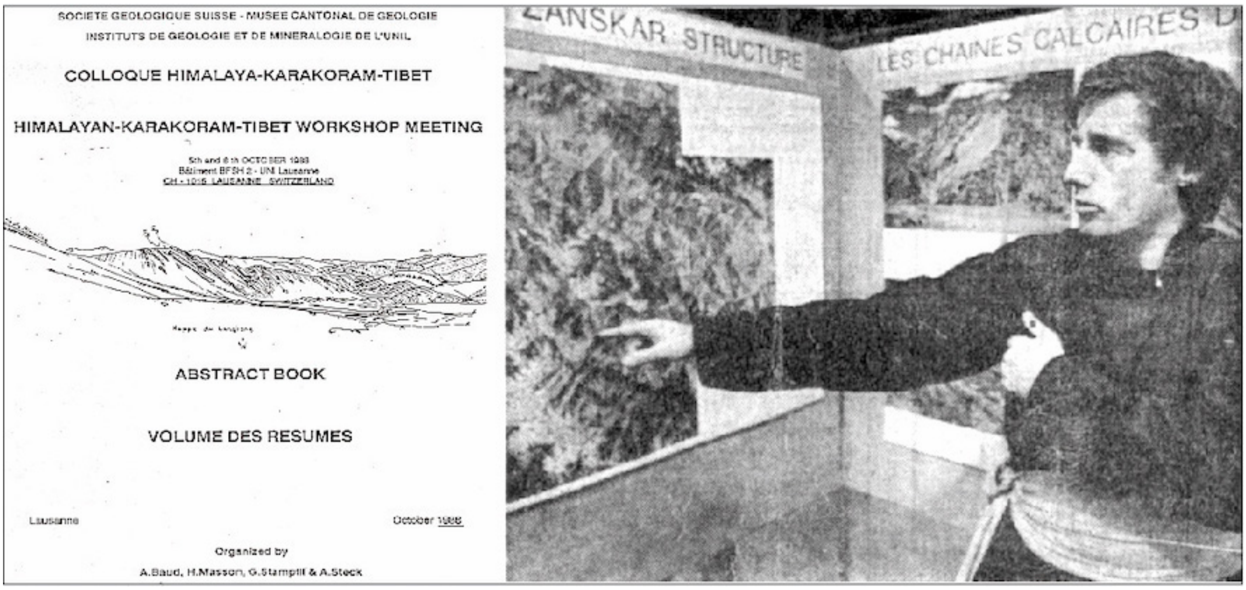

Figure 10 : La couverture du volume des résumé à gauche et à droite, l'auteur commente l'exposition publique consacrée à l'Himalaya du Ladakh.

3 – La troisième période : 1993-2003

Au cours de la troisième période, de 1993 à 2003, j'ai participé à trois nouveaux programmes internationaux de recherche jusqu'à ma retraite de directeur du musée de Géologie, et deux nouvelles lignes de recherche ont été lancées.

3.1 – Participation de 1993-2003 au projet Pangea de la Commission de Géologie sédimentaire globale (C-GSG)

Invité à l'Université du Kansas à Lawrance pour la réunion inaugurale du projet scientifique international Pangea, j'ai présenté un aperçu des recherches européennes consacrées à l'océan disparu Tethys, et été invité à coproduire les cartes de Pangea. Le projet Pangea a été publié dans le document spécial 288 de la Société géologique d'Amérique (GSA).

Il a alors été décidé que le projet Pangea se concentrerait sur la période la plus récente d'accrétion et de dispersion des supercontinents, c'est-à-dire du Carbonifère au Jurassique, lorsque les continents ont fusionné et que le climat de la Pangée a subi une grande glaciation (Baud, 1992 ; Ross et al., 1992). Ce projet faisait partie du programme de l'Union Internationale des Sciences Géologiques (UISG) sur la Géologie sédimentaire mondiale (P-GSG) présidé par B. Beauchamp et j›ai collaboré avec lui pour ce projet sur la Pangée. Les réunions étaient souvent associées à des congrès internationaux. Du 15 au 19 août 1993, le projet Pangea a organisé la « Tethys evolution during Pangea time Conference » à Calgary, organisée par B. Beauchamp et A. Embry. On m›a demandé d›être responsable de l›un des thèmes de la conférence, et j›ai organisé et dirigé l›une des sessions. J›ai également donné deux conférences (Baud, 1993a, b) et contribué à la présentation de quatre posters (Baud et al.,1993 ; Marcoux & Baud, 1993 ; Marcoux et al. 1993b, d).

La réunion suivante de Pangea s'est tenue pendant le symposium international sur le Permien, du 28 au 31 août 1994 à Guiyang, en Chine, dans le cadre du projet 359 du PICG. En tant que membre du comité scientifique, j'ai présenté un exposé à ce congrès et participé aux travaux de la sous-commission internationale sur la stratigraphie permienne (Baud, 1994)

Du 9 au 11 mars 1999, une réunion Pangea s'est tenue à Wuhan en Chine (Fig. 11).

Figure 11 : Photo de groupe à la réunion Pangea 1999, à Wuhan (Chine).

Les actes de la conférence, comprenant 14 articles (175 pages), ont été publiés sous la forme d'une publication spéciale de l'Université de Wuhan. J'ai présidé une session et présenté un exposé sur nos résultats concernant la limite Permien-Trias en Oman (Baud et al., 1999).

Durant le Congrès international sur la stratigraphie du Carbonifère et du Permien à Calgary en août 1999, une session spéciale Pangea, organisée par B. Beauchamp, a été consacrée à la transition entre le Permien et le Trias et notre groupe de recherche y a présenté 3 résumés (Baud, 1999 ; Beauchamp et al., 1999).

En 2001, la dernière réunion du projet Pangea s'est tenue à Mascate en Oman. Grâce à la coordination avec les organisateurs de la Conférence internationale sur la géologie d'Oman, et avec le Ministère du commerce et de l'industrie, le symposium de deux jours Pangea a débuté le 14 janvier, au cours duquel 18 communications orales et 5 posters ont été présentés. Une excursion sur le terrain a été organisée avant la conférence et une excursion de quatre jours (Fig. 12) après la conférence (Baud, Béchennec et al., 2001a, b).

Figure 12 : Participants et organisateurs de l'excursion post-Congrès Pangea, sur la Géologie d'Oman en 2001avec F. Béchenec et J. Marcoux, 3ème et 4ème depuis la gauche, au milieu.

Nous étions dix collègues à préparer les deux guides de terrain très détaillés. Les actes ont été publiés dans un numéro spécial de Palaeogeography, Palaeoclimatology, Palaeoecology (PPP -Baud et al., editors, 2003), et avec Jean Marcoux et Benoit Beauchamp nous avons rédigé un compte-rendu du symposium (Baud et al., 2001c) et présenté 4 communications (Baud & Beauchamp, 2003 ; Krystyn et al., 2003 ; Kozur et al., 2001a, b). Au chapitre 3.9, nous donnons le détail d'un nouvel axe de recherche présenté à cette réunion.

3.2 – Participation de 1993 à 1999 au programme de recherche géologique international Peri-Tethys

À la suite du programme « Tethys » relaté dans le chapitre 2.6, un nouveau programme géologique international appelé Peri-Tethys a été lancé. En même temps, il y avait un nouveau projet 343 du PICG, « Corrélation des bassins épicratoniques de la Téthys ». En collaboration avec Sylvie Crasquin et Jean Marcoux, nous avons créé un groupe de recherche PICG sur la crise de la limite Permien-Trias et l'avons également incorporé au programme Peri-Tethys. Ma proposition d'études de terrain et d'échantillonnage dans la région de Dobrogea -Roumanie (projet Peri-Tethys 95-32) a bénéficié d'un soutien financier. Lors de la deuxième réunion, en septembre 1993 à Bucarest, après des travaux de terrain, , j'ai donné une conférence (Baud, 1993) et dirigé une session. Nous avons publié en 1997 un ouvrage collectif sur le Trias inférieur de la Dobrogea, qui est devenu une référence (Baud, éditeur, 1997 ; Baud et al., 1997).

Une nouvelle collaboration a vu le jour avec le Dr Lucia Angiolini de l'Université de Milan (Fig. 12a), qui est venue au musée de Géologie de Lausanne pour étudier les brachiopodes du Permien d'Oman collectés par notre étudiant post-doctorat Alain Pillevuit. En janvier 1995, nous avons été invités à participer à une expédition internationale financée par le programme Péri-Téthys, qui s'est déroulée dans le Sultanat d'Oman afin de résoudre les problèmes de la stratigraphie, de la paléontologie, sédimentologie et paléoécologie de la succession permienne de la région de Huqf (Fig. 13). Au cours de cette expédition, une grande collection de brachiopodes a été échantillonnée le long de deux sections stratigraphiques à Saiwan et Wadi Haushi, étudiée et publiée par Lucia Angiolini avec l'ensemble de notre équipe de recherche (Angiolini et al., 1995, 1997).

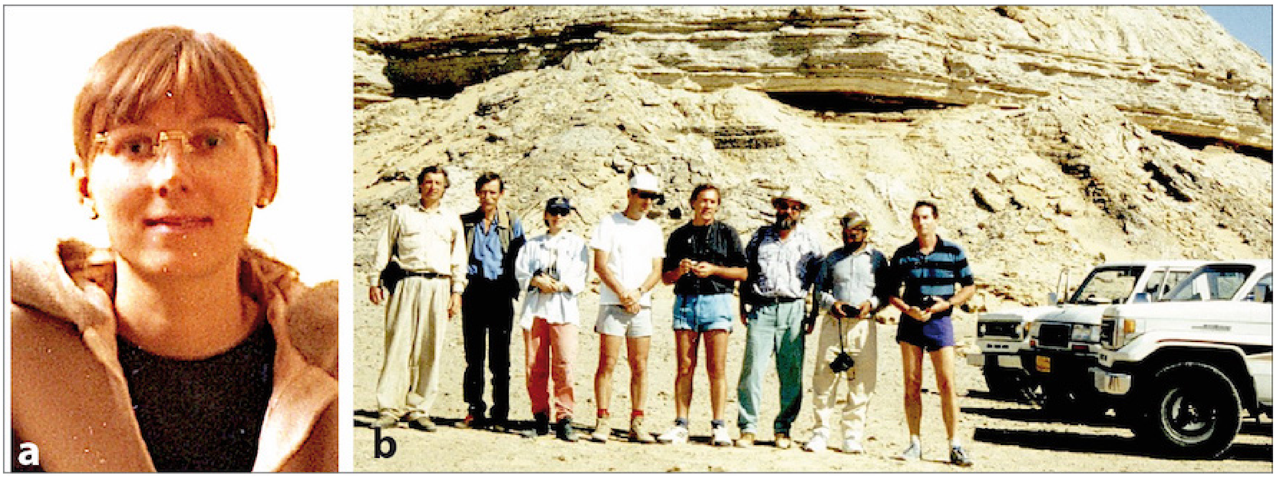

Figure 13 : a) Dr L. Angiolini, b) Notre équipe de recherche Peri-Tethys sous les affleurements Permien de Huqf, en1995. A gauche, à côté de l'auteur, J. Marcoux and L. Angiolini.

Dans la suite du programme Péri-Téthys, une campagne de terrain a été organisée dans la péninsule ukrainienne de Crimée au cours de l'été 1996. Avec Jean Marcoux, nous nous sommes rendus ensemble à Simferopol (Ukraine), pour des travaux de terrain sur les blocs permiens et triasiques de Crimée, avec l'aide des Professeurs Galina Kotlyar et Yuri Zakharov. Notre étude nous a conduits à la datation des blocs exotiques de ce territoire ukrainien, à leur comparaison avec les blocs exotiques de Kürée (nord de la Turquie) et à la publication complète des résultats en 1999, après examen des lames minces dans le laboratoire de Galina Kotlyar (Kotlyar et al., 1999).

3.3 – En 1994, seconde invitation du Prof. Benoit Beauchamp à participer à l'étude des stratotypes du Trias inférieur du Haut-Arctique canadien, avec de nouvelles découvertes

Invité à nouveau par Benoît Beauchamp, j'ai eu l'occasion de travailler avec le professeur Charles Henderson de l'Université de Calgary (Fig. 14).

Avec lui, nous avons échantillonné pour l'étude des conodontes les localités du Haut-Arctique contenant des Otoceras sur les îles Axel Heiberg et Ellesmere, afin de résoudre la controverse sur les corrélations entre ammonoïdes et conodontes au passage Permien-Trias. Les résultats ont été publiés dans les Actes du Congrès géologique de Pékin de 1996 (Henderson and Baud, 1997) : au-dessus des conodontes de Changxing, l'espèce de conodonte *parvus* apparaît au milieu de la zone supérieure *d'Otoceras* (*Otoceras boreale*).

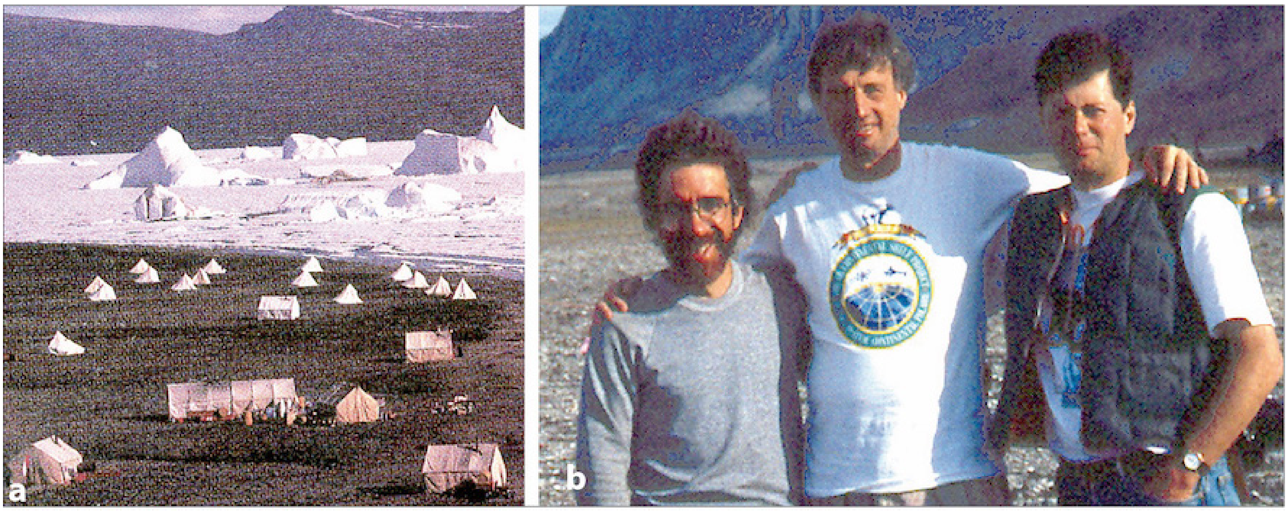

Figure 14 : Otto Fjord sur l'île d'Ellesmere, a) notre camp, b) notre équipe de recherche avec B. Beauchamp (à gauche) et C. Henderson (à droite).

Plus tard, en 1999, Amalia Spina, doctorante de Perrugia (Italie), a obtenu une bourse de l'UNECO pour réaliser une étude palynologique de la collection arctique permienne- triasique de notre musée de Géologie de Lausanne et a présenté, avec Simonetta Cirili ses résulats dans Cirilli et al. (2001).

Benoît Beauchamp m'a associé à son point de vue sur le développement des roches siliceuses biogènes du Permien supérieur dans les régions arctiques et, avec le changement climatique, à sa disparition à la transition Permien-Trias. Après sa présentation au symposium Pangea 2001, nous l'avons publié (Beauchamp & Baud, 2002), et cet article a rapidement obtenu un indice de citation élevé.

3.4 – Acceptation par le Fonds national suisse pour la recherche scientifique (FNSRS) d'un premier projet sur l'étude des isotopes du Carbone dans les couches du Trias précoce, recherches entreprises avec Viorel Atudorei (1994-1999)

Avec la nomination de Zachary Sharp comme nouveau professeur à Lausanne, un nouveau laboratoire d'étude des isotopes du Carbone est devenu opérationnel et des programmes de recherche ont pu être soumis. Pour approfondir l'outil chimio-stratigraphique développé avec les Professeurs W. Holser et M. Magaritz, j'ai proposé en 1993 un projet de recherche sur les études isotopiques du Trias au FNSRS et j'ai obtenu un soutien financier en 1994 pour Viorel Atudorei de Roumanie. Avec lui, une importante collection de roches triasiques de la Dobrogea (Roumanie) a été rassemblée et étudiée en détail en 1994, mais aussi lors de la réunion de terrain Péri-Téthys de 1995.

Avec les échantillons précédemment collectés dans les Salt Ranges et au Cachemire, Viorel Atudorei a commencé à étudier les isotopes du Carbone de la transition Permien-Trias sur la marge nord-indienne de la Téthys (Atudorei et al., 1995a, b; Baud et al., 1995a, b, 1996).

Le soutien financier de ce Fonds nous a permis de poursuivre les recherches sur le terrain et l'échantillonnage du Permien-Trias dans le Sultanat d'Oman de 1996 à 1998 avec l'aide de Jean Marcoux (Paris) et d'Alain Pillevuit, étudiant post-doctorat de Lausanne (Baud et al., 1999).

En 1997, le Dr. H. Bucher a fourni à Viorel Atudorei une collection de roches carbonatées bien datées du Trias inférieur de la région de Spiti (Inde du Nord) et Viorel Atudorei a pu établir la première courbe isotopique complète du Carbone du Trias inférieur, publiée dans un chapitre de son travail de doctorat. Il a brillamment défendu sa thèse sous ma direction (Atudorei, 1999). Le professeur Z. Sharp ayant obtenu un nouveau poste et un grand laboratoire isotopique à l'Université du Nouveau Mexique à Albuquerque (USA), Viorel Atudorei y a pris un poste de chercheur et y a entamé une carrière fructueuse.

3.5 – Acceptation par le FNSRS d'un deuxième projet sur l'étude des isotopes du Carbone dans les couches du Trias précoce, recherches entreprises avec Sylvain Richoz (1999-2004)

Le nouveau projet FNSRS que j'ai soumis, « La stratigraphie isotopique et l'étude de la matière organique des sédiments marins du Permien supérieur au Trias moyen », a été approuvé, et Sylvain Richoz, géologue diplômé de Lausanne, a été choisi pour occuper le poste d'assistant doctorant au musée de Géologie. En septembre 1999, Jean Marcoux et moi-même l'avons accompagné pour commencer des travaux de terrain dans la région d'Antalya (sud-ouest de la Turquie). Tous les trois, nous avons poursuivi ces travaux de terrain en 2000 jusqu'en 2003, en élargissant nos recherches à la région d'Alanya et du Taurus (Baud et al., 2001). Avec Jean Marcoux et Sylvain Richoz, nous avons poursuivi, en janvier 2000, les travaux de terrain sur le Permien-Trias d'Oman (Baud et al., 2001 ; Richoz et al., 2001a, b) et lui-même y a conduit des excursions (Fig 15)

Avec l'ouverture de l'Iran aux chercheurs étrangers, une partie de notre équipe de recherche avec Richoz a eu l'opportunité de passer un mois en mai 2002, avec l'aide du Service géologique d'Iran, pour effectuer des recherches sur le terrain avec collecte d'échantillons dans des coupes très connues du Permien-Trias du centre et du nord-ouest de l'Iran (Richoz et al., 2010).

Ceci a permis à Sylvain Richoz d'apporter une nouvelle synthèse en chimiostratigraphie, d'aborder une compréhension de l'évolution de trois marges néotéthysiennes (Iran, Turquie et Oman) au cours de la fin du Permien et du début du Trias et de rédiger sa thèse de doctorat qu'il a brillamment achevée et défendue en 2004, mettant en évidence la grande instabilité du réservoir de carbone inorganique au cours du Trias inférieur (Richoz, 2006).

3.6 – De président à ancien-président de la Sous-commission de stratigraphie du Trias (SST), passage de témoin (1993-2003)

En tant que président de la Sous-commission de stratigraphie du Trias (SST), j'ai participé en juin 1993 aux travaux de terrain du groupe de travail sur la limite Anisien-Ladinien dans les Dolomites italiennes et en Hongrie. En novembre, j'ai été invité à Heidelberg pour la réunion du groupe d'étude européen sur les bassins triasiques.

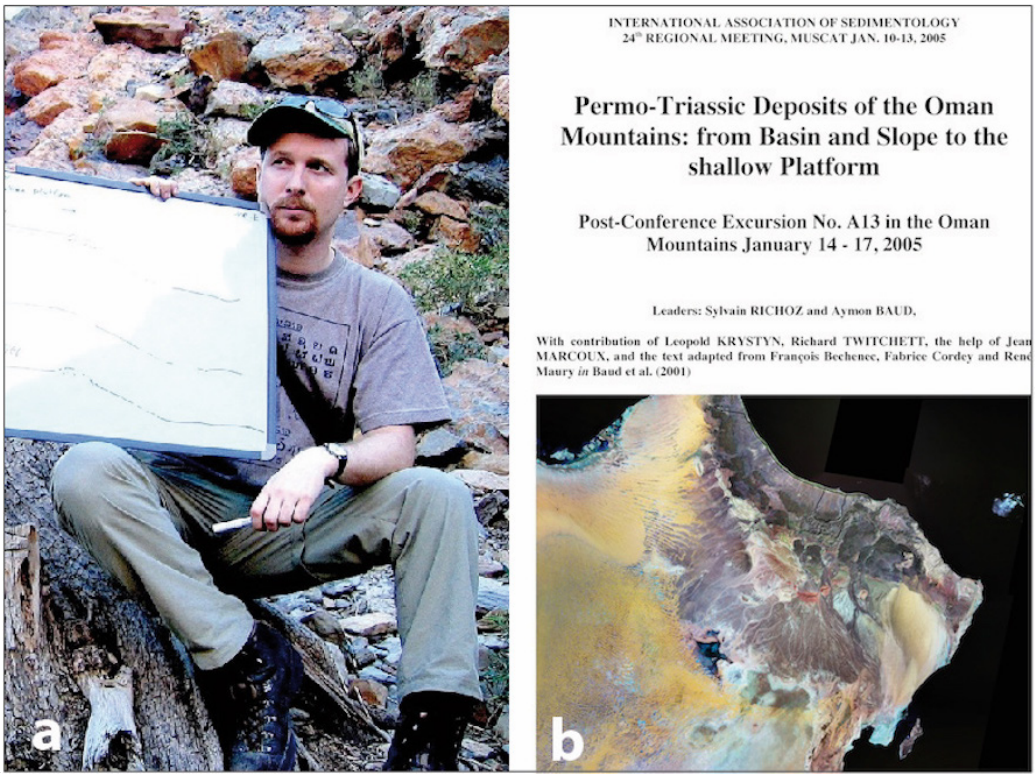

Figure 15 : a) Excursion en Oman, Sylvain Richoz montre un tableau, b) Page de couverture du livret guide de l'excursion A13 du congrès de sédimentologie de 2005.

En 1994, j'ai dirigé la réunion plénière de la SST organisée pendant la conférence « Shallow Tethys 4 », du 9 au 12 septembre 1994, à Albrechtsberg (Fig. 16) près de Vienne, Autriche (Baud. 1994b). Au cours de cette conférence, une réunion du groupe de travail sur la limite Permien-Trias (PTBWG) et une réunion régionale du projet 359 du PICG ont également été organisées.

Figure 16 : Le nouveau président, M. Gaetani à côté de l'ancien, à Albrechtsberg en 1994.

En 1995, le professeur Maurizio Gaetani de l'Université de Milan a été élu nouveau président et deviendra mon successeur. En 1996, la SST a tenu une réunion plénière lors du 30e Congrès géologique international (CGI) à Pékin et la Commission internationale de stratigraphie (ICS) a approuvé la nomination de Maurizio Gaetani en tant que nouveau président de la SST. Chargé de stimuler le groupe de travail sur la limite entre le Permien et le Trias, M. Gaetani a reçu en 1999 un vote positif des membres votants du SST sur le choix de Meishan pour le stratotype global (GSSP) de cette limite. En 2000, lors du 31ème IGC à Rio de Janeiro, la Commission Internationale de Stratigraphie (ICS) a ratifié ce GSSP et a approuvé Mike Orchard de Vancouver (Canada) comme nouveau président de la SST, succédant à Maurizio Gaetani.

En 2001, une cérémonie inaugurale du monument GSSP est organisée dans la carrière de Meishan pendant le symposium international sur «Le stratotype global de la limite Permien-Trias et les événements paléozoïques-mésozoïques» dirigé par Hongfu Yin. J'ai fait un exposé lors du symposium et l'article rédigé avec Benoît Beauchamp sur la redéfinition du sous-étage Griesbachien a été publié dans les actes du symposium (Baud & Beauchamp, 2003).

3.7 – Participation au Congrès Géologique International (CGI) à Pékin (Chine) du 4 au 14 août 1996, et celui de Rio de Janeiro (Brésil) du 7 août au 3 septembre 2000

Désigné par le Comité suisse du PICG comme chef de la délégation suisse auprès de l'Union Internationale des Sciences Géologiques (UISG), j'ai participé aux travaux du 30ème Congrès Géologique International, congrès qui s'est tenu à Pékin du 4 au 14 août 1996. J'ai été responsable d'une des sessions du Symposium sur «la limite Permien-Trias et la corrélation globale du Trias» et j'ai présenté 2 communications (Baud, 1996; Baud et al., 1996). J'ai suivi les sessions de travail de l'UISG et participé aux sessions plénières du Congrès. En tant qu'ancien président de la sous-commission de stratigraphie du Trias, j'ai participé activement à l'assemblée générale de la sous-commission qui s'est tenue dans le cadre du congrès et j'ai participé à une excursion Permien-Trias traversant la Chine occidentale.

J'ai fait part de mes recherches au journaliste G. Olivieri qui a publié l'article ci-dessous (Fig. 17).

En 2000, j'ai participé au 31e Congrès géologique international à Rio de Janeiro (Brésil) du 7 août au 3 septembre. Orateur invité au Symposium Permien-Trias, j'ai fait un exposé sur les variations géochimiques à la limite Permien-Trias (Baud, 2000). J'ai suivi les sessions et, lors de l'assemblée générale de l'Union internationale des sciences géologiques (UISG) qui s'est tenue pendant le congrès, j'ai été nommé président de sa Commission de la Géologie sédimentaire globale (C-GSG). Après le congrès, j›ai participé à une excursion officielle, avec la géotraversée des Andes entre Mendoza (Argentine) et Vina del Mare (Chili). A mon retour du Congrès et de l'excursion j'ai rédigé un rapport complet sur l'accomplissement du programme de cette commission de 1987 à 2002, qui a été publié dans le volume 25/4 du périodique Episode (Baud, 2002).

3.8 – A partir de 1996, un deuxième axe de recherche a été mis en route, avec la mise en évidence des constructions algo-microbiennes qui ont suivi la grande extinction

Suite à l'étude des lames minces des collections du Permien-Trias hébergées au musée de Géologie de Lausanne et provenant des localités suivantes: Curuck Dagh (Turquie), Vedi et Sovetchen (Arménie) et Abadeh (Iran), j'ai reçu l'aide précieuse de Simonetta Cirilli, professeur de paléontologie à l'Université de Perrugia. C'est grâce à sa contribution que le concept d'une réponse à la Grande

Extinction consistant en une résurgence soudaine des accumulations algo-bactériennes a été affirmé dans un poster et un résumé que nous avons présentés en 1996 à la réunion du projet 380 du PICG à Göttingen en Allemagne sur la «biosédimentologie des accumulations microbiennes» (Baud & Cirilli, 1996). La publication que nous avons préparée et à laquelle nous avons associé Jean Marcoux a paru dans Facies en1997 (Baud et al., 1997), et a eu un impact considérable. Ce nouveau concept a été suivi par des centaines de publications qui ont pleinement confirmé cette résurgence dans toutes les régions intertropicales d'alors où affleurent et sont étudiées les couches de calcaire marin de la transition entre le Permien et le Trias.

Science trop méconnue, la géologie répond à des questions fondamentales

Grandes éruptions, extinctions massives, changements climatiques, une promenade au musée favorise la réflexion.

NATURE
PAR Guido OLIVIERI

Le sol, on le foule constamment, dans un certain sens on lui doit tout, et pourtant on parle remarquablement peu de géologie. A grand tort, car, ainsi que le remarque Aymon Baud, directeur du Musée cantonal de géologie, «dans ce pays où on a tant de richesses sous les yeux, il serait possible avec un peu plus de connaissances d'appréhender avec plus de profondeur ce qui est caché dans la silhouette des montagnes, sous le miroir d'un lac».

Ces connaissances, le musée, qui a quitté le Palais de Rumine pour accompagner la section de sciences de la terre à Dorigny, entend bien les diffuser progressivement, notamment par le biais de la Société des amis du Musée de géologie et à l'occasion d'une grande exposition qui doit se tenir l'année prochaine. Un déménagement qui l'éloigne certes du centre-ville mais s'explique par un souci de rationalisation — tout est désormais réuni sur un seul étage — et d'économie, puisque cela permet une bibiothèque ainsi que d'autres services communs, l'approfondissement des sciences de la terre impliquant l'usage de toutes sortes d'appareils coûteux.

Mais revenons-en à l'essentiel. Il y a l'histoire de l'humanité, puis celle combien plus longue de la vie en général, enfin celle, «milliardaire», de la planète. Avec la géologie, c'est donc une autre dimension du temps que l'on aborde, moins documentée sans doute au niveau de la paléontologie, car les fossiles sont des exceptions, mais beaucoup plus au niveau de la planète. Tout cela figurant dans le demi-million de pièces que possède le musée, fruit de fouilles dans le canton, mais aussi d'échanges, car il s'agit d'un jeu continu de vases communicants, l'étude d'un bout d'alpe permettant de comprendre l'ensemble qui a lui même donné les premières clés à l'étude sectorielle.

Dans ce vaste contexte, le rôle d'un musée est multiple, souligne Aymon Baud, des collections, qui sont les archives, au rôle pédagogique que sont les expositions et les prêts, comme par exemple celui de bois fossiles à l'arboretum de l'Aubonne. Mais pour mieux comprendre encore le rôle actif de la géologie on peut, par-delà le problème complexe des datations, souligner son rôle dans la compréhension des changements climatiques ou des séismes, ce qui n'est pas une musique du passé, mais bien l'outil indispensable pour tenter de prévoir, voire de ménager l'avenir.

Car si l'homme a sa part de responsabilité dans l'effet de serre, l'étude du climat dépasse, et de loin, ce «simple» phénomène. Pour le géologue, ces variations sont logiques, explicables et cent fois constatées. Ainsi il connaît le rôle considérable du volcanisme dans la concentration de CO_2, il relève que si la calotte glacière fond il y aura plus d'eau froide ouverte, des espaces qui sont des «puits» de CO_2 en l'absorbant massivement...

Et puis il y a aussi le problème des extinctions massives, une vingtaine, dont cinq de grande ampleur, dont on rappelle souvent celle qui a vu disparaître les dinosaures et moins celle du permien-trias au cours de laquelle 95% des espèces ont pourtant disparu. Une nouvelle et colossale période éruptive comme celle qui s'est produite à cette période — un tiers de la Sibérie sous la lave — pourrait-elle se répéter, et avec quelles conséquences? Les archives de la terre sont en fait les seules données scientifiques, encore certes bien lacunaires, qui existent. D'où la nécessité, urgente, de poursuivre les recherches sur le terrain en profitant d'instruments sans cesse plus performants.

G. OL.

Aymon Baud, conservateur du Musée cantonal de géologie, parmi quelques-unes des pièces actuellement conservées à l'UNIL dans les abris de la PC. Olivieri

Le géologue sur le terrain

Comment pratique-t-on sur le terrain? Aymon Baud donnera, mardi 26 mars à 17 h 15, en l'amphitéâtre du bâtiment de biologie de l'Université de Lausanne, sous les auspices de la Société vaudoise de sciences naturelles, une conférence sur le thème: «A l'aube des temps secondaires, recherches dans l'Arctique septentrional sur les îles d'Ellesmere et d'Axel Heiberg».

Cette mission a été réalisée, sur invitation du Dr Benoit Beauchamp, du Service géologique du Canada, à partir d'Otofiord, par 82 degrés de latitude nord, pour étudier le détail de l'histoire des mouvements marins à l'aube des temps secondaires et celle des écosystèmes qui ont survécu à la grande crise de la limite permien-trias.

Plusieurs raisons font de ces îles un terrain d'observation de choix pour les géologues stratigraphes et sédimentologues. En effet, en dehors des zones de névés permanents et de glaciers, les terrains sont dégagés durant l'été, faisant partie de ces régions du désert arctique qui ne connaissent que de faibles précipitations annuelles. D'autre part un soulèvement contemporain de celui des Alpes fait apparaître, par basculement, plus de 12 km de couches superposées, déposées de manière presque continue depuis le milieu de l'ère primaire (trois cent cinquante millions d'années) jusqu'au milieu de l'ère tertiaire, il y a quarante millions d'années.

G. OL.

Figure 17 : article publié dans le journal 24Heures du 23 mars 1996.

Afin de comprendre les débuts de cette vie microbienne qui est apparue sur Terre au Néoprotérozoïque il y a 3,5 milliards d'années et celle de l'édification des monticules de boue du Paléozoïque, je me suis alors engagé à participer à trois congrès avec excursion sur le terrain :

1. En 1998, du 30 novembre au 6 décembre, j'ai participé à l'excursion d'Atar en Mauritanie. Janine Bertrand-Sarfati et Alexis Moussine-Pouchkine ont animé cette excursion de six jours sur le terrain pour examiner les constructions stromatolitiques d'âge méso- à néo protérozoïque de l'Adrar mauritanien et leur environnement. J'ai discuté avec les spécialistes mondiaux de ces carbonates construits et j'ai pris des photos de colonnes de stromatolithes géants (voir texte anglais).
2. En 1999, le projet 380 du PICG a organisé une excursion à Ouarzazate au Maroc (Fig. 18), du 23 septembre au 2 octobre. Les examens des monticules carbonatés dévoniens dans la région de Ouarzazate ont été d'un grand intérêt et le guide de terrain est devenu une référence.
3. La troisième excursion sur le terrain en Namibie, en 2002, a eu lieu juste avant le 16ème congrès international de sédimentologie à Johannesburg (Afrique du Sud). Consacrée au prélude de l'explosion cambrienne elle a montré, sous la direction de John Grotzinger, l'enregistrement de la vie et des environnements dans le groupe protérozoïque terminal de Nama. Cette excursion m'a

permis de découvrir les roches sédimentaires protérozoïques terminales les mieux exposées et les plus fossilifères le long de la côte ouest de la Namibie.

Figure 18 : Participants à l'excursion d'Ouarzazate au Maroc, en 1999.

Grâce à cette possibilité unique d'examens de microbialites diverses et variées, les recherches sur le terrain qui ont suivi ont été riches en nouvelles découvertes sur les peuplements algo-microbiens post-extinctions et les équipes de recherche ont été renouvelées comme montré dans la période suivante.

3.9 – La découverte sur le terrain en Oman de métazoaires qui ont échappé à la grande extinction permet l'ouverture d'une troisième ligne de recherche qui se poursuivra dans les périodes suivantes

Lors de l'étude géologique du Wadi Wasit avec Jean Marcoux en 1997, j'ai collecté des ammonoïdes près d'un gros bloc calcaire appartenant à un olistostrome charriant de gros blocs récifaux permiens. J'ai transmis ces ammonoïdes au spécialiste, le professeur Leopold Krystyn de Vienne.

Il les a déterminées et avec la découverte tout à fait surprenante de l'âge Griesbachien (Trias basal) de ces fossiles, il est allé échantillonner le bloc calcaire à mes coordonnées géographiques précises en décembre 1998. En février 1999, je suis retourné sur le terrain et Jean Marcoux m'a rejoint pour échantillonner ce bloc. Avec le travail paléontologique effectué par Krystyn et l'étude en coupe mince au musée de Géologie sur l'échantillon prélevé, nous avons pu reconnaître pour la première fois un calcaire du Trias basal construit par des accumulations de fossiles dans une eau de mer bien oxygénée, alors qu'elle était réputée anoxique. J'ai donné une conférence sur la transition Permien-Trias d'Oman en mentionnant cette étude durant la réunion Pangea de Calgary (Baud, 1999). Lors de la réunion en Oman sur la Pangée en 2001 (chap. 3.1), Krystyn a présenté un exposé et un poster (Krystyn et al., 2001), et les résultats communs de notre nouvelle équipe de recherche ont été publiés (Krystyn et al., 2003). Cette publication a attiré beaucoup d'attention et un indice de citation élevé. Notre collègue Richard Twitchett de l'Université de Plymouth nous a rejoints pour l'étude de ce bloc, unique à l'époque (Twitchett et al, 2004).

3.10 – Une formation continue sur le terrain en Oman offerte à une association d'étudiants en géologie de l'Université de Lausanne

Préparé avec Jean Marcoux et Sylvain Richoz pour l'association lausannoise des étudiants en géologie Pangea, nous avons présenté la richesse géologique du paysage omanais à 13 étudiants en master participant activement avec leur professeur de géologie structurale, Henri Masson, durant le mois de janvier 2002 (Fig. 19). Le Dr Heinz Kozur (Hongrie) s'est joint au voyage et a publié ses observations (Kozur, 2002).

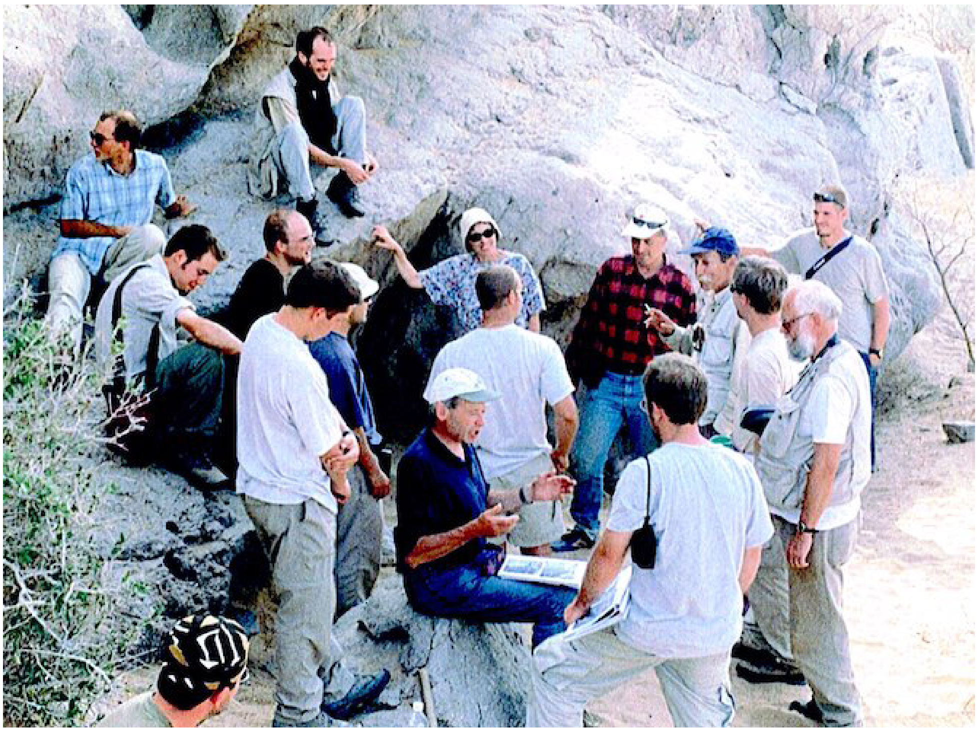

Figure 19 : Explications géologiques données par H. Masson, au milieu, aux étudiants lausannois.

3.11 – Exposition du musée avant ma retraite en 2003 : une vue historique sur les derniers siècles de découverte de la Haute Asie

Pour terminer ma vie active avant la retraite sur une bonne note, et sur un sujet qui me tient à cœur, j'ai préparé avec une petite équipe soudée (P. Forêt & S. Gorshenina) une exposition historique sur la découverte de la Haute Asie par des scientifiques au cours des derniers siècles dans notre bâtiment d'exposition temporaire. Elle commençait avec Victor Jacquemond (1801-1832) qui fut le premier à découvrir des fossiles en Spiti-Himalaya. Nous avons également donné des informations sur les explorateurs géologues de l'Himalaya F. Stoliczka et C. L. Griesbach qui ont été les premiers à découvrir la faune d'Otoceras du Trias basal, et nous avons terminé avec Arnold Heim et Augusto Gansser et l'exploration géologique secrète de ce dernier au Tibet du Sud en 1936. Un ouvrage très illustré a été édité en français (Fig. 20) aux éditions Olizane, « La Haute Asie telle qu'ils l'ont vue. Explorateurs et scientifiques de 1820 à 1940 », 152 pages et 120 illustrations (Baud et al., 2003).

En conclusion à cette troisième période, je veux d'abord remercier le personnel du Musée, préparateurs et secrétaires qui m'ont accompagné et aidé et également le personnel de laboratoire, les bibliothécaires et le préparateur de lames minces du département des Science de la Terre pour leurs contributions.

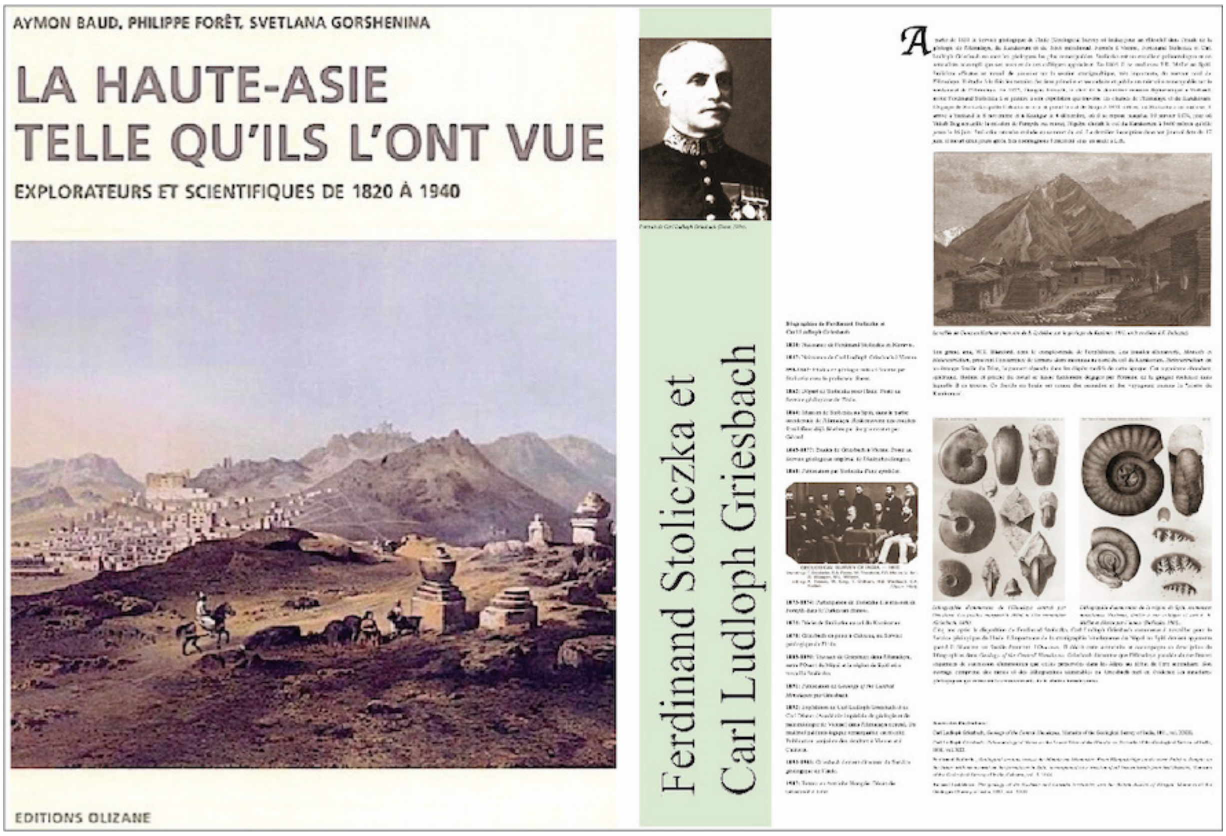

Figure 20 : Couverture de l'ouvrage cité à gauche, et page sur Stoliczka et Griesbach à droite.

Le musée de Géologie de Lausanne a acquis, avec ses nouvelles collections sur le Permien-Trias et les publications associées, une réputation internationale, qu'en prenant ma retraite de directeur, j'ai pu transmettre à mon successeur et à toute l'équipe du Musée.

4 – La quatrième période : fin 2003-2010

Avec ce départ à la retraite de la direction du musée de Géologie de Lausanne, l'abandon d'une administration chronophage et sans obligations professionnelles, j'ai pu me lancer dans de nouvelles périodes de recherche sur le terrain et dans les rédactions qui étaient en attente.

Avec mes connaissances en stratigraphie du Permien-Trias, celles en chimiostratigraphie des isotopes du Carbone et mon expérience scientifique sur les accumulations microbiennes, j'ai pu également prendre le temps de rédiger un grand nombre d'observations et de résultats non publiés, issus de travaux de terrain antérieurs, de commencer de nouvelles études sur de riches collections du Permien-Trias avec leurs coupes minces. J'ai pu aussi donner des réponses positives à ma participation aux travaux de terrain des équipes de recherche qui m'y ont associés. L'étude des isotopes du Carbone s'est poursuivie avec Sylvain Richoz, et la ligne de recherche sur les microbialites a donné lieu à des publications avec S. Cirilli, J. Marcoux et S. Richoz (Baud et al., 2003). Celle sur les métazoaires du Trias basal s'est poursuivie avec R. Twitchett associé à J. Marcoux et L. Krystyn. Durant cette quatrième période, j'ai également pu mettre à la disposition de mes collègues et groupes de recherche toute mon expérience dans l'organisation de congrès avec stages sur le terrain et symposiums associés. La coopération avec les paléontologues-stratigraphes des ammonoïdes triasiques s'est poursuivie avec Jean Guex et Hugo Bucher, sur les conodontes avec Leopold Krystyn, Alda Nicora, et depuis 2007 avec Charles Henderson. Quant à Sylvie Crasquin et, à partir de 2008 avec Marie-Beatrice Forel, elles ont collaboré à l'étude des ostracodes, et Lucia Angiolini à l'étude et la détermination des brachiopodes sur les terrains que nous avons étudiés.

4.1 – Participation au Congrès géologique international (IGC), Florence, 18-29 août 2004, et au Congrès paléontologique (IPC), Pékin, 16-21 juin 2006

En septembre 2003, je me suis rendu à un Symposium sur la géochronologie et la cyclostratigraphie du Trias à St. Christina (Dolomites, Italie). Au cours de cette conférence, la théorie de la cyclostratigraphie de Goldhammer a fait l'objet de vives critiques.

J'ai participé en 2004 avec Sylvain Richoz, au 32ème Congrès Géologique International à Florence (Italie). Il y a présenté les résultats de son doctorat sur la chimio-stratigraphie isotopique du Carbone des coupes du passage Permien-Trias de l'Iran, de la Turquie et d'Oman (Richoz & Baud, 2004). A la session « Late Permian-Early Triassic events » j'ai présenté un exposé sur une revue des données géochimiques connues des sédiments marins de l'intervalle de transition Permien-Trias (Baud & Richoz, 2004).

Pendant le congrès, Bruce Wardlaw de Boise (USA) a présenté son programme de base de données Permien-Trias appelé Chronos, un système d'information chronostratigraphique, et il m'a invité à participer au printemps 2005 à la réunion Paleostrat à Boise, aux États-Unis.

A son invitation, j'ai participé, les 1 et 2 mai 2005, à la réunion de travail du projet Permian-Trias de Paleostrat à Boise et j'y ai donné deux conférences, dont l'une concernait les importantes collections Permien-Trias hébergées au musée de Géologie de Lausanne (Baud, 2004), puis j'ai publié sur les changements géochimiques au passage Permien-Trias (Baud, 2005).

En 2006, avec Patrice Moix de Lausanne et Sylvie Crasquin de Paris, nous nous sommes rendus au deuxième congrès international de paléontologie à Pékin, du 16 au 21 juin. J'ai donné une conférence (Baud et al., 2006), et participé à deux autres présentations, l'une avec l'équipe de recherche de Dave Botjer et l'autre avec l'équipe de Hongfu Yin (Marenco et al., 2006 ; Yin et al., 2006, 2007a, b). Du 22 au 28 juin nous avons participé à l'excursion qui examinait la succession du Paléozoïque supérieur au Trias de l'Himalaya tibétain et les événements géologiques importants le long de la route menant du Népal à Lhassa (Fig. 21).

Figure 21 : Les participants au col de Jiacuola (Tibet).

À cette occasion, nous avons pu organiser le premier échantillonnage de la section Tulong du Trias inférieur avec son calcaire à ammonoïdes rouges. Après cette étude, nous avons été inclus dans les articles publiés en 2009 et 2010 sur cette section tibétaine de Tulong (Brühwiler et al., 2009 ; Forel et al., 2011).

4.2 – Poursuite de la collaboration avec Jean Marcoux en Oman de 2003 à 2007

Comme précédemment, la recherche en Oman a bénéficié de l'aide inestimable, de l'hébergement et de l'amitié de Françoise et Jean-Paul Breton vivant à Ruwi/Mascate. De son côté, le Dr. Hilal bin Mohammed Al-Azri, Directeur Général des Minéraux jusqu'en 2005, s'est montré très favorable à nos projets de recherche en Oman.

En janvier 2004, nous avons poursuivi nos recherches sur le terrain avec Jean Marcoux et Hugo Bucher dans la région de Nizwa et avons rejoint nos collègues L. Krystyn de Vienne et R. Twitchett de Plymouth pour travailler et prélever des échantillons dans la région de Wadi Maqam, afin de préparer une grande excursion sur le terrain prévue au Congrès de sédimentologie de 2005.

Lors de la 24ème réunion de l'Association internationale des sédimentologues (IAS), qui s'est tenue du 10 au 13 janvier 2005 à l'Université Sultan Qaboos à Al Khod près de la capitale Mascate, notre équipe de recherche a présenté un exposé (Baud et al., 2005).

Mes collègues H. Droste, C. Robin, F. Guillocheau, P. Razin & F. Bechennec m'ont associé pour préparer le livret guide sur « L'évolution mésozoïque de la marge téthysienne d'Oman ». Nous avons dirigé cette excursion du 4 au 9 janvier (Baud et al., 2005). Avec S. Richoz, L. Krytyn, J. Marcoux et R. Twitchett, nous avons rédigé le guide d'excursion sur la naissance et le développement précoce de la marge téthysienne d'Oman du Permien moyen au Trias moyen avec une approche géochimique et sédimentologique, puis nous avons dirigé avec succès l'excursion du 14 au 17 janvier (Richoz et al., 2005).

4.3 – Poursuite de la collaboration avec Jean Marcoux en Turquie de 2003 jusqu'à son décès en 2008, et visite à Spiti/Himalaya (2004) et en Nouvelle-Zélande (2006)

En Turquie, les contacts de Marcoux avec l'Université d'Isparta nous ont beaucoup aidés pour les études de terrain et les permis d'échantillonnage.

Déjà une semaine après ma retraite, en septembre 2003, j'ai été invité par l'équipe de recherche de Marcoux à effectuer des études sur le terrain sur la succession Permien-Trias de Hazro, dans le sud-est de la Turquie. Nous avons échantillonné une section permienne complète, et les foraminifères permiens ont été publiés par Gaillot & Vachard, (2007)et Gaillot et al. (2016). Avec Sylvie Crasquin, nous avons aussi étudié la transition Permien-Trias (Baud et al., 2016).

Du 25 juin au 10 juillet 2004, avec des amis archéologues et J. Marcoux, nous avons participé au congrès avec excursion sur le terrain dans la province himalayenne de Spiti, au nord de l'Inde (Fig. 22), ceci dans le cadre du projet 467 du PICG sur le Trias. À cette occasion, nous avons étudié et échantillonné des coupes de la limite entre le Permien et le Trias, avec les couches historiques à *Otoceras*, de la base du Trias définies en Himalaya.

En mai 2005, nous sommes retournés avec J. Marcoux dans le sud-ouest de la Turquie pour une étude de terrain sur la paléotectonique permienne de la région de Curuck Dagh. Nous avons découvert d'importants déplacements et discordances intra-Permien-Trias et, pour la première fois, des pseudomorphoses d'ikaite sur des calcaires du Permien moyen (Baud et al., 2005).

Figure 22 : A gauche, Jean Marcoux ; à droite, avec son épouse Noëlle sur la route de Spiti,.

En mars 2006, nous avons décidé, avec J. Marcoux, de participer en Nouvelle- Zélande à un congrès avec excursion sur le terrain du projet 467 du PICG sur les dépôts de radiolarite du Permien-Trias de l'île du Nord et à la réunion du symposium InterRad 11 à Wellington (Fig. 23), où nous avons présenté deux exposés (Baud et al., 2006 ; Marcoux et al., 2006).

Figure 23 : Repas principal d'InterRad 11 à Wellington en Nouvelle Zélande, avec à droite Jean et Noëlle Marcoux et à gauche je suis avec mon épouse Monique.

L'excursion a offert l'occasion unique au monde d'observer une section continue de radiolarite du Permien tardif au Trias moyen sur l'île d'Arrow Rock. En observant les affleurements situés sous les radiolarites du Permien supérieur, j'ai découvert un socle de pillow-lavas recouvert d'un calcaire rouge à ammonoïdes, ce qui m'a permis d'envisager une future ligne de recherche développée au chap. 5.11.

En septembre 2007, Patrice Moix, doctorant à Lausanne, nous a demandé, à Marcoux et à moi, de jeter un coup d'œil sur son travail de terrain de thèse dans une région proche de Mersin, au sud de la Turquie. Puis avec Marcoux nous sommes allés dans la région d'Alanya et avons découvert une nouvelle coupe du Permien-Trias à Oznurtepe. En raison de la maladie qui le rongeait, ce fut mon dernier travail sur le terrain avec lui.

En mai 2008, à cause de cette maladie, nous avons poursuivi le travail de terrain sans lui dans la région de Curuck Dagh, au sud-ouest de la Turquie, mais avec toute une équipe emmenée par Sylvie Crasquin, avec sa doctorante M.B. Forel et un invité le professeur Steve Kershaw de Brunnel (UK) intéressé par les microbialites qu'il va par la suite publier (Kershaw et al., 2011, 2012). J'ai encadré V. Verna, doctorant de L. Angiolini, pour l'échantillonnage des brachiopodes permiens, avec la professeure Alda Nicora de Milan (Verna et al., 2011).

Le 17 juin 2008, alors que nous revenions de ce travail de terrain, nous avons appris la nouvelle de décès soudain de Jean Marcoux, ce qui nous a tous profondément touchés. Certains d'entre nous ont participé à la cérémonie de son enterrement au célèbre cimetière du Père Lachaise à Paris. Ayant vécu plus de 25 ans d'aventures géologiques avec lui, écrivant ensemble, organisant des réunions ou des expéditions géologiques, j'ai préparé des articles d'hommages (Baud, 2008, 2009 a, b, 2010), et participé à la préparation de réunions sur le terrain en Turquie et Oman en son souvenir (voir chapitre suivant).

4.4 – Le nouveau projet 572 du PICG va permettre de rendre hommage à Jean Marcoux lors de deux conférences que nous avons organisées sur les terrains qu'il a tant parcourus

En 2008, le nouveau projet sur le Trias du PICG, le no 572 dirigé par Zhong Qiang Chen (Australie), vise à étudier la reconstitution des écosystèmes après l'extinction en masse de la fin du Permien et à analyser les archives sédimentaires et fossiles par le biais d'étude de biostratigraphie, de paléontologie, de paléoécologie, de sédimentologie, de géochimie et de biogéochimie.

Du 2 au 6 septembre 2009, la deuxième réunion annuelle du projet 572 s'est tenue à Antalya, dans le sud de la Turquie. En tant que co-organisateur, j'ai dirigé la session d'ouverture dédiée à la mémoire de Jean Marcoux avec le rappel de toute sa carrière scientifique et de ses travaux sur le Permien et le Trias de la région. Une réunion d'une journée, le 3 septembre, a été organisée à la Faculté d'ingénierie de l'Université Akdeniz à Antalya avec l'aide d'E. Kosun, professeur adjoint. L'excursion sur le terrain de trois jours (Fig 24), que nous avons organisée avec S. Crasquin et S. Kershaw du 4 au 6 septembre a examiné toutes les coupes du passage Permien-Trias découvertes avec Jean Marcoux (Crasquin et al., 2009).

Figure 24 : A gauche, photo des participants à l'excursion prise dans la carrière de Demirtas près d'Alanya avec Noëlle Marcoux debout au milieu ; A droite, couverture du livret guide en hommage à Jean Marcoux.

C'est du 20 au 26 février 2010 que la troisième réunion annuelle du PICG 572 s'est tenue en Oman, organisée conjointement avec la professeure Michaela Bernecker de l'Université allemande GUtech à Mascate. La conférence d'une journée et demie a permis de rappeler tous les travaux effectués par Jean Marcoux en Oman. Elle a été suivie d'une excursion de quatre jours et demi organisée avec O. Weidlich, B. Beauchamp, L. Krystyn, A. Nicora, C. Henderson, S. Richoz, F. Cordey et R. Twitchett, qui a offert aux participants l'opportunité de visiter les magnifiques affleurements du Sultanat d'Oman permettant un accès inégalé aux unités de transition entre le Permien et le Trias que nous avions étudiées le long de la marge du Gondwana de la Téthys (Baud, & Bernecker, editors, 2010).

4.5 – Poursuite de la collaboration avec Benoit Beauchamp, Charles Henderson et Steve Grasby, avec travaux en Oman et en Turquie de 2003 à 2010

En 2003, le numéro spécial Pangea, édité avec B. Beauchamp, est publié (Baud, Beauchamp et al., 2003).

En 2004, j'ai participé à la conférence conjointe I.C.E. 2004 CSPG qui s'est tenue à Calgary, au Canada, et l'équipe de recherche de Beauchamp m'a inclus dans deux documents présentés à cette occasion (Beauchamp et al., 2004a, b).

En 2005, B. Beauchamp m'a invité à donner une conférence à ses étudiants à l'Université de Calgary. La collaboration avec Benoît Beauchamp, Charles Henderson et Steve Grasby se poursuit avec, sur ma proposition, des recherches sur le Permien-Trias en Oman : ils reçoivent un soutien financier pour cela. En conséquence, en janvier 2006, l'équipe de recherche de Beauchamp, ainsi que Noel James et Alda Nicora de Milan ont pu venir travailler sur le terrain dans différents affleurements clés du Permien-Trias depuis le centre d'Oman jusqu'à Wadi Maqam à la frontière des Émirats.

En août 2006, j'ai participé à la conférence sur le Trias boréal à Longyearbyen, Svalbard, Norvège arctique, et présenté un exposé sur les couches riches en bryozoaires du Trias inférieur que j'ai découverts sur l'île d'Ellesmere lors des travaux de terrain effectués en 1994 avec B. Beauchamp dans le Haut-Arctique canadien. L'article réalisé avec l'équipe de recherche de Beauchamp, associée au spécialiste des bryozoaires, le professeur Hans Nakrem d'Oslo, a été publié dans Polar Research (Baud et al., 2007).

En janvier 2009, nous nous sommes rendus avec B. Beauchamp dans différents affleurements clés du Permien-Trias d'Oman pour préparer le deuxième congrès avec excursion sur le terrain du projet 572 du PICG, Sultanat d'Oman pour 2010.

En septembre 2009, après le congrès avec excursion sur le terrain du PICG 572, à Antalya en Turquie, j'ai conduit Charles Henderson à la découverte d'affleurements permiens-triasiques qui n'avaient pas été inclus dans le programme.

En Oman en 2010, l'équipe de recherche de Beauchamp participe activement au deuxième congrès avec excursion sur le terrain du PICG 572 (Fig. 25).

4.6 – Nouvelle collaboration avec le professeur Dave Botjer de l'UCLA, ses doctorants Sara Pruss, Pedro Marenco, et avec les Dr Frank Corsetti et Dr Adam Wood (Los Angeles, USA) de 2003 à 2008

En 2003, j'ai invité Sara Pruss et Dave Botjer à découvrir les unités Permien-Trias des montagnes d'Antalya au sud de la Turquie. Ils ont prélevé des échantillons et sont revenus très enthousiastes en me proposant de les rejoindre pour une étude sur le Trias de la côte ouest des Etats-Unis en 2004 (Fig 26).

Les échantillons ont été analysés pour les isotopes de soufre associés au carbonate par F. Marenco, qui a envoyé un résumé commun pour la réunion annuelle 2004 de la GSA (Marenco et al., 2004).

En mai 2004, j'ai rejoint l'équipe Permien-Trias de l'UCLA pour une excursion sur les affleurements du Trias inférieur du Nevada et de la Californie, où nous avons échantillonné les calcaires du Trias inférieur de Darwin Hills.

En mars 2005, j'ai rejoint Sara Pruss pour une étude sur le Trias des Darwin Hills et des Muddy Mountains près de Las Vegas.

Figure 25 : Notre équipe de recherche sur le bloc de Wasit en Oman en 2010, avec de gauche à droite, C. Henderson, B. Beauchamp, l'auteur et L : Krystyn.

Figure 26 : a) D. Botjer au Kopet Dagh dans le sud de la Turquie, en 2003, b) Notre équipe de recherche dans le Nevada en 2004, avec à l'horizon les Monts Darwin, c) S. Pruss mesure l'épaisseur des couches dans la région de Bagolino en Italie du Nord.

En mai 2005, nous nous sommes retrouvés au Symposium sur la chronostratigraphie du Trias et le rétablissement de la biodiversité, à Chaohu, en Chine du Sud. À partir des travaux précédents avec S. Pruss et S. Richoz, j'en ai présenté les résultats, alors que l'équipe de Marenco et Corsetti exposait les anomalies isotopiques du soufre au cours de la transition Permien-Trias (Baud et al., 2005 ; Marenco et al., 2005).

La même année, D. Botjer était responsable d'un volume spécial du C.R. Palevol sur «The Triassic recovery, the dawn of the modern biota» et nous avons eu l'occasion de publier un article avec Marcoux et Richoz sur les roches calcimicrobienne du Trias basal de Turquie (Baud et al., 2005), et un autre article avec l'équipe de Corsetti et Marenco associée à Richoz sur «Un résumé des enregistrements isotopiques de Carbone au Trias inférieur» (Corsettti et al., 2005).

En 2006, nous avons écrit une synthèse basée sur les travaux de terrain avec S. Pruss, D. Botjer et F. Corsetti, de 2003 et 2005 et qui montrent les réponses post-extinction entre le sud de la Turquie et l'ouest des États-Unis (Pruss et al., 2006).

Toujours avec S. Pruss, nous nous sommes rendus en 2008 à Bolzano, au Symposium sur la paléoclimatologie du Trias, où nous avons présenté un exposé et avons poursuivi nos recherches dans le Trias moyen des Alpes du Sud dans la région de Bagolino (Pruss, & Baud, 2008).

En janvier 2005, j'ai proposé à Adam Wood, alors qu'il participait à la réunion de l›IAS à Mascate (Oman), de débuter des recherches en commun sur le terrain et de prélever des échantillons dans les calcaires rouges à ammonoïdes du Trias de l'affleurement de Baid. Après des analyses de ces calcaires faites à UCLA, A. Wood m'a associé pour présenter le résultat de ses recherches lors de la réunion annuelle de la GSA en 2006 à Philadelphie, aux États-Unis (Woods & Baud, 2006). En 2008, notre article intitulé «Anachronistic facies from a drowned Lower Triassic carbonate platform of Oman Mountains» a été publié dans la revue Sedimentary Geology (Woods & Baud, 2008). Puis c'est avec Sylvain Richoz que nous avons poursuivit ces recherches en 2013 (voir chap. 5.5).

4.7 – La pratique de consultant en géologie, de 2005 à 2008

Pour répondre à la demande d'expertise scientifique dans mon domaine d'expérience, j'ai ouvert à la demande de mon collègue et ami Jean-Paul Breton en charge d'Exploration Consultants à Mascate en Oman, un bureau de consultant en géologie, nommé BGC (Baud Geological Consultant). Pour lui et avec lui en mai 2005, j'ai entrepris l'expertise des brèches permiennes du Jebel Akhdar pour l'exploitation de marbre coloré.

En mars 2007, il m'a été demandé de fournir un livret-guide et de diriger une excursion de trois jours sur la succession de carbonates permiens et triasiques du plateau de Saiq (Oman) pour des experts de la compagnie Total SA (Baud, A. 2007).

En janvier 2008, avec J.P. Breton, j'ai entrepris l'expertise de la brèche triasique des montagnes Wasa au sud de Wadi Maqam dans le nord-ouest d'Oman.

4.8 – Participation à la formation continue en géologie pour les enseignants des lycées français (CBGA)

Thierry Juteau, professeur honoraire de géologie à l'Université de Brest et spécialiste des roches ophiolitiques, animateur de la formation continue des professeurs de lycée (CBGA), m'a demandé en 2009 de coanimer une excursion géologique dans les montagnes d'Oman et de co-écrire le guide de terrain (Juteau et al., 2009). Avec des amis, j'ai rejoint l'excursion fin octobre 2009 et été associé à y présenter les meilleurs affleurements permettant de comprendre la géologie d'Oman et de l'enseigner aux élèves de lycée (Fig. 27). La poursuite de cette participation est présentée au chapitre 5.12.

Figure 27 : Excursion des professeurs de Lycées français (CBGA) en Oman en 2009, a) Explication de la géologie sur le Plateau de Saiq, b) Les responsables de l'excursion avec de gauche à droite, J. P. Breton, T. Juteau et l'auteur.

5 – La cinquième période : 2011-2023

La coopération avec les paléontologues-stratigraphes s'est poursuivie avec Jean Guex et avec son élève Hugo Bucher devenu professeur à l'Université de Zurich, avec Thomas Brühwiler son assistant, tous spécialistes des ammonoïdes triasiques. Quant au Dr. Nicolas Goudemand et les doctorants Morgane Brosse et Marc Leu, ils se sont spécialisés sur l'étude des conodontes du Trias inférieur de la Chine du Sud, du Cachemire et d'Oman. Les Dr. Francis Hirsch et Pablo Placensia, eux connaissent bien les conodontes du Trias moyen et ils m'ont aidé à apporter un nouveau regard sur la stratigraphie du Trias moyen des Préalpes suisses et de là du Trias moyen ouest européen.

Les axes de recherche précédents ont été appliqués à de nouvelles zones d'étude sur le terrain, ce qui a permis de faire des découvertes et d'ouvrir des perspectives plus larges. L'occasion s'est présentée de participer à l'organisation de congrès internationaux avec excursion sur le terrain grâce à des collègues locaux ouverts d'esprit qui ont accueilli favorablement les réunions des projets d'étude du Trias du PICG de l'UNESCO.

Les programmes d'éducation continue en géologie se sont poursuivis avec les enseignants de lycées français et se sont ouverts aux doctorants lausannois.

5.1 – Poursuite des travaux de terrain en Oman de 2011 à 2015, d'abord avec l'équipe de recherche autrichienne avec Sylvain Richoz, Leopold Kystyn et Rainer Brandner, puis avec l'équipe de recherche canadienne avec Benoit Beauchamp, Steve Grasby et Charles Henderson

En janvier 2011, juste un an après la réunion du PICG 572, nous avons poursuivi nos travaux de terrain avec L. Krystyn dans la région du Batain (Oman) et J. Guex nous a rejoints (Fig. 28).

Lorsque j'ai découvert le bloc fossilifère d'Asselah, et déterminé l'ammonoïde silicifié présente à la surface, les deux spécialistes ont approuvé l'âge Griesbachien (Trias basal) de ce bloc. Comme ils n'étaient pas intéressés par son étude, j'en ai parlé à mon ami Hugo Bucher. Du coup, il a ouvert à Zurich un nouveau projet de recherche pour ses étudiants doctorants que nous relatons dans le chapitre 5.2 suivant.

En décembre 2011, j'ai participé avec S. Richoz au congrès Permien-Trias de l'EAG à Koweit City et nous y avons donné deux exposés et un compte-rendu de la réunion de l'année précédente faite en Oman (Baud et al., 201 ; Richoz et al., 2011).

En 2012, je me suis rendu avec lui à la conférence internationale sur la Géologie de la plaque de l'Arabie et des montagnes d'Oman qui s'est déroulée du 7 au 9 janvier 2012, à l'Université Sultan Qaboos, à Mascate, Oman, et nous y avons donné 2 exposés en collaboration avec nos collègues canadiens (Baud et al., 2012a, b ; Richoz et al., 2012a, b).

Figure 28 : Discussion sur le terrain près d'Asselah avec de gauche à droite, J. Guex, L. Krystyn et l'auteur.

Les travaux de 2013 sur Oman avec S. Richoz sont présentés dans le chapitre 5.5.

En 2015, B. Beauchamp a eu la possibilité de m'accompagner sur le plateau de Saiq et dans la plaine de Batain pour approfondir notre étude sur la succession des calcaires permiens.

Certains de nos résultats ont été présentés à la 31ème réunion internationale de sédimentologie de l'IAS, du 22 au 25 juin 2015, à Cracovie, en Pologne (Beauchamp et al., 2015) et en 2018 au Congrès international de sédimentologie, qui s'est tenu dans la ville de Québec au Canada (Beauchamp & Baud, 2018).

5.2 – Participation aux travaux de terrain en Oman avec le professeur Hugo Bucher et ses doctorants de l'Université de Zurich dès 2011

La nouvelle collaboration avec Hugo Bucher, ses doctorants et assistants a pris forme en 2011 et s'est prolongée jusqu'à aujourd'hui (2023) au sein du groupe de recherche Paléo C4 -Sinergia des Universités de Zurich, Lausanne et Genève, groupe mis en route depuis 2018.

À chaque expédition, le travail de terrain en Oman a bénéficié du support de la professeure Michaela Bernecker de l'Université GuTech pour la garde et le maintien de nos outils de travail. C'est avec elle et Oliver Weidlich que nous avons organisé les excursions du « 12th International Symposium on Fossil Cnidaria and Porifera » qui s'est tenue à GuTech en 2015 (Baud & Weidlich 2015).

Nous avons débuté sur le terrain en novembre 2011 avec la doctorante Asa Frisk et le Dr Nicolas Goudemand, pour étudier et échantillonner le bloc d'Asselah dans le Batain (Fig. 29), ceci juste 10 mois après ma découverte de ce bloc fossilifère avec L. Krystyn et J. Guex (Baud et al., 2015 ; Brosse et al., 2019).

Le projet « The Permian mass extinction and Early Triassic recovery of Eastern Oman », préparé par Hugo Bucher et financé par le FNSRS, nous a permis d'aller prospecter en décembre 2012 les régions de Wadi Wasit et du Batain en Oman.

Figure 29 : Région d'Asselah dans le Batain (Oman), a) H. Bucher démonte un nouveau bloc fossilifère du Trias inférieur, b) Photo du bloc d'Asselah, c) N. Goudemand et l'auteur avec les collines d'Asselah dans le fonds.

Nous avons repris ensemble l'étude du Batain en décembre 2013 et en janvier 2015 avec Romain Jattiot, doctorant. En janvier 2017, un autre doctorant d'Hugo Bucher, Marc Leu, nous a rejoints pour étudier les calcaires rouges à ammonoïdes du Wadi Musjah (Baud, 2013a) et les nouveaux blocs triasiques dans le Batain. La même année, en décembre, nous sommes allés dans la région du Djebel Rabat et en janvier 2018, nous avons poursuivi l'échantillonnage des blocs fossilifères du Trias inférieur du Batain avec Thomas Brühwiler.

Depuis 2018, des échantillons d'Oman conservés au musée de Géologie de l'Université de Zurich sont étudiés par des équipes de professeurs et de doctorants de Lausanne et de Zurich pour les déterminations paléontologiques et une étude géochimique, avec le soutien financier du programme Synergia du FNSRS. Les principaux résultats ont été présentés lors de conférences internationales et publiés dans des articles et des chapitres de thèse de Morgane Brosse (Brosse et al., 2017), Marc Leu (Leu et al., 2021), Zoneibe Luz (Luz et al., 2023), Franziska Blattmann (2023) et Oluwasser Edward (2023).

5.3 – Ma collaboration avec la Société géologique d'Oman (GSO) s'est poursuivie de 2011 à 2015.

Lors de mon séjour à Mascate, mes propositions de conférence ou d'excursion sur le Permien ou le Trias ont toujours été les bienvenues à la Société géologique d'Oman. C'est pourquoi en janvier 2011, après ma conférence sur le sujet « Oman oases : contrasting carbonates sediments on the Gondwana margin in the immediate aftermath of the Permian-Triassic boundary mass extinction », j'ai proposé aux membres de la Société de les conduire à la section de Buda'yah, le seul endroit où l'on trouve les radiolarites du Permien moyen reposant directement sur un substrat de laves en coussins (Fig. 3'). En tant qu'enregistrement unique des environnements océaniques du Permien moyen au Trias précoce de la Néotéthys, cette section a été proposée comme localité du patrimoine géologique d'Oman (Baud, 2011).

En novembre 2013, c'est l'unité appelée la Khuff, bien connue en géologie pétrolière et affleurant dans les montagnes d'Oman, qui a fait l'objet de ma conférence.

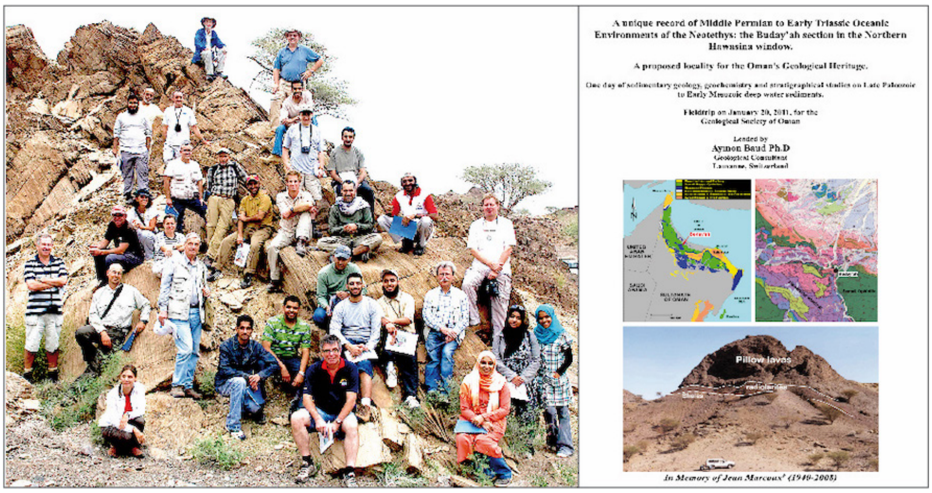

Figure 30 : La section de Buda'yah : à gauche les participants de l'excursion de la Société géologique d'Oman sont assis sur l'affleurement de calcaire du Trias inférieur. A droite la couverture du livret guide de cette excursion (janvier 2011).

En février 2015, j'ai donné une conférence sur nos découvertes d'oasis de vie qui apparaissent dans les suites immédiates de la grande extinction et qui affleurent dans les montagnes d'Oman et dans le Batain (Baud et al. (2014).

5.4 – Participation aux travaux de terrain dans le Guangxi en Chine du Sud et au Cachemire dans le nord- ouest de l'Inde avec Hugo Bucher et ses doctorants

Parmi les zones de travail sur le terrain, la province de Guangxi, au sud de la Chine, était nouvelle pour moi et l'accueil réservé par Kuang Guodun, retraité du Bureau de Géologie de Guangxi, m'a impressionné, car il a dirigé l'équipe de recherche de Bucher dans les affleurements clés du Permien-Trias de sa région qu'il connaissait très bien.

Nous avons débuté nos travaux de terrain en mars 2011 avec H. Bucher, sa doctorante Åsa Frisk et l'aide précieuse de Kuang Guodun. Nous avons étudié et échantillonné plus de 15 coupes de la limite Permien-Trias (PTB) et du Trias inférieur dans le nord de la province de Guangxi (Fig. 31).

Figure 31 : Notre équipe de recherche en Chine en 2011, a) Kuang Guodun, notre guide et collègue chinois, b) Åsa Frisk échantillonne, c) Hugo Bucher et l'auteur en pleine discussion.

Les travaux de terrain suivants ont eu lieu en février 2012 avec la même équipe et une nouvelle doctorante, Morgane Brosse. Nous avons étendu la recherche à l'ensemble de la province de Guangxi, en étudiant et en échantillonnant près de 15 nouvelles coupes du Permien-Trias (Brosse et al., 2013, 2015, 2016 ; Bagherpour et al., 2015, 2016, 2017 ; Hautmann et al., 2015).

L'une d'entre elles, la section de Shangan, a ouvert une nouvelle voie de recherche présentée au chapitre 5.5.

L'ouverture du Cachemire indien en 2012, après un black-out de 25 ans, m'a offert l'opportunité d'encadrer sur le terrain les doctorants zurichois avec l'aide précieuse du professeur Ghulam Bhat de l'Université de Jammu, en Inde (Fig. 32). Nous avons débuté nos études de terrain en mai 2012 avec le Dr Nicolas Goudemand, spécialiste des conodontes et les doctorants Marc Leu, Max Meier et Morgane Brosse, et je les ai conduits avec G. Bath à la fameuse coupe géologique de Guryul Ravine pour travailler sur la limite Permien-Trias et sur la succession des couches du Trias inférieur (Brosse et al., 2013, 2017). Nous avons également effectué des prospections dans la région à la recherche de nouvelles coupes du Permien-Trias.

Figure 32 : a) Notre équipe de recherche au Cachemire en 2012, b) Prof. Ghulam Bhat et l'auteur.

Toujours avec l'aide de Ghulam Bath, notre équipe de recherche est retournée en octobre 2013 pour poursuivre l'étude du Trias inférieur de Guryul Ravine. Certains résultats ont été présentés au 19ème Congrès International de Sédimentologie 2014, 18-22 août, Genève, Suisse (Leu et al., 2014), et notre équipe avec H. Bucher a publié 2 articles (Brosse et al., 2017 ; Leu et al., 2023). Les principaux résultats des travaux en Chine et au Cachemire ont permis à Morgane Brosse (2017) et à Marc Leu (2021) de passer avec succès leur doctorat avec des publications concernées qui impliquent toute l'équipe de recherche.

5.5 – Suite aux travaux en Chine, un nouvel axe de recherche s'ouvre : le calcaire à stromatactis post-extinction témoin de la présence d'éponges

En 2011, en découvrant un calcaire à stromatactis post-extinction du Trias basal avec l'équipe de recherche d'Hugo Bucher dans la section de Dongpan, au sud de la Chine, j'ai réalisé, sachant que dans les roches carbonatées les éponges sont à l'origine d'une structure appelée stromatactis, que ces éponges avaient survécu à la grande extinction de la fin du Permien. Cela m'a permis de préparer des résumés et des exposés que j'ai présentés d'abord lors de la réunion de clôture du PICG 572, du 1er au 4 juin 2012 à Egger en Hongrie (Baud et al., 2012a), puis lors de la 29e réunion de l'IAS sur la sédimentologie du 10 au 13 septembre à Schladming en Autriche (Baud et al., 2012b), ainsi que lors de la réunion annuelle de la GSA à Charlotte aux États-Unis (Baud et al., 2012c) et enfin lors du

Symposium sur l'extinction de masse de la fin du Permien et le changement climatique extrême, qui s'est tenu à Wuhan en Chine (Baud et al., 2013).

En 2013, j'ai à nouveau travaillé, cette fois avec S. Richoz, sur les lames minces des calcaires rouges à ammonoïdes du Trias de l'affleurement de Baid et ses stromatactis abondants (cf. chapitre 4.6). Nous avons alors préparé un résumé intitulé « The Smithian (Early Triassic) red ammonoid limestone of Oman, refuge for sponge-microbial build-ups during a recovery phase » et un exposé pour la réunion annuelle de la GSA en 2013 à Denver. USA (Baud & Richoz, 2013), et au 12ème symposium international sur les cnidaires et les porifères fossiles du 8 au 12 février 2015, à l'Université GuTech de Mascate en Oman (Baud & Richoz, 2015).

5.6 – Participation aux travaux de terrain en Iran et en Turquie avec Sylvain Richoz, l'équipe de recherche autrichienne avec Leopold Krystyn, Rainer Brandner et les nouveaux venus, Micha Horacek, Katrin Heindel et Paul Beckman

L'invitation à retourner en Iran en 2011 a été possible grâce au Dr Taipeh Mohat, géologue en chef du Service géologique d'Iran, qui nous a invités et a dirigé notre équipe de recherche sur le terrain. Avec l'équipe de recherche autrichienne, nous avons bénéficié d'un soutien financier de 2 semaines, du 16 au 30 mai, et avons eu l'occasion d'étudier cinq sections de la limite Permien-Trias dans le Zagros et en Iran central (Fig. 33). Ces travaux de terrain nous ont permis d'approfondir des observations sur la géométrie et la disposition spatiale des accumulations microbiennes dans les sections clés de Shareza et d'Abadeh au centre de l'Iran, comme expliqué au chapitre 5.8. Les premiers résultats de nos recherches ont été présentés à la réunion annuelle de la GSA en 2013 à Denver, USA (Heindel et al., 2013) et publié en 2015 (Heindel et al., 2015).

Figure 33 : L' équipe de recherche à Abadeh, avec notre collègue Taipeh Mohat, 4ème.

En Turquie, le Dr Erdal Kosum, de l'Université d'Antalya, nous a aidés et a participé activement, en avril 2012, à nos recherches sur le terrain dans la région d'Antalya et d'Alanya sur le Permien et le Trias (Heindel et al., 2018b).

5.7 – Participation aux travaux de terrain en Arménie avec Sylvain Richoz, l'équipe de recherche autrichienne et la doctorante Evelyn Friesenbichler

C'est en 2014 que l'équipe de chercheurs autrichiens, Sylvain Richoz, Leopold Krystyn et Rainer Brandner avec Evelyn Friesenbichler, doctorante, a reçu une invitation de l'Académie arménienne des sciences pour commencer des recherches sur le Permien et le Trias en Arménie. Ils m'ont invité à participer à ces recherches, étant donné que je connaissais et y avais échantilloné deux coupes géologique 30 ans auparavant. La professeure Lilit Sahakyan nous a accueillis à Erevan, et a aidé notre équipe à organiser la recherche et nous a ensuite guidés sur le terrain. Du 27 septembre au 7 octobre 2014, nous avons durant 10 jours étudié les sections clés du passage Permien-Trias (Fig. 34).

Figure 34 : Sylvain Richoz explique à Lilit Sahakyan son point de vue sur la succession stratigraphique de la coupe examinée le 3 octobre 2014.

Notre travail d'équipe et mes connaissances antérieures sur le terrain ont permis de mieux comprendre la complexité des constructions faites par les microbialites post-extinction et le rôle des éponges, anticipant ainsi notre nouvelle ligne de recherche dont je fais état dans le chapitre suivant 5.8.

En 2015, épaulé par notre équipe de recherche sur l'Arménie, nous avons envoyé un résumé et préparé un exposé intitulé « Giant microbial buildups of earliest Triassic in Armenia », au 2e Congrès international sur la stratigraphie qui s'est tenu du 19 au 23 juillet 2015 à Graz en Autriche (Friesenbichler et al., 2015). J'ai présenté un poster à la conférence Goldschmidt-2015 à Prague en Tchéquie (Baud et al., 2015), et un exposé à la réunion annuelle 2016 de la GSA à Denver aux États-Unis (Friesenbichler et al., 2016). Nous avons pris les contacts pour la réunion projetée du projet IGCP 630 en Arménie à Erevan, que nous présentons au chapitre 5.9.

5.8 – Une ligne de recherche élargie : le lien entre les éponges métazoaires post-extinction et les accumulations microbiennes

Avec Katrin Heindel, dans le cadre du travail de thèse d'Evelyn Friesenbichler et en association avec William Foster, chargé de recherche, un nouveau venu dans notre équipe de recherche austro-arménienne, nous avons envoyé en 2016 un résumé et préparé un exposé sur « Earliest sponge-microbialite reefs on Neotethys platform margins in the Early Triassic » à la Conference Dolomieu sur les plateformes carbonatées à Selva di Val Gardena en Italie et à la réunion annuelle de la GSA à Seattle en 2017 (Heindel et al., 2016, 2017, 2018b). En 2018, Evelyn Friesenbichler, avec notre équipe de recherche, a préparé un manuscrit intitulé « Sponge- microbial build-ups from the lower-most Triassic Chanakhchi section in southern Armenia » qui a été publié (Friesenbichler et al., 2018). Un autre manuscript sur « The formation of microbial-metazoan bioherms and biostromes following the latest Permian mass extinction », a été publié dans Gondwana Research, (Heindel et al., 2018a).

En 2018, j'ai étendu notre découverte arménienne des récifs de microbialites à éponges du Trias précoce à la succession de microbialites du Trias basal découverte en Iran central et j'ai proposé nos nouvelles données dans un résumé et un exposé au Congrès sédimentologique international qui s'est tenu du 12 au 17 août 2018 à Québec au Canada (Baud et al., 2018). Avec S. Richoz, nous avons développé le thème de faciès spécifique à une époque donnée, appliqué aux microbialites à éponges et avons envoyé un résumé et présenté un exposé au 3e Congrès international sur la stratigraphie, à Milan, du 2 au 5 juillet 2019 (Baud & Richoz, 2019). En 2020, avec Micha Horacek comme nouveau venu, j'ai finalisé notre manuscrit commun sur « Sponge takeover from End-Permian mass extinction to early Induan time : Records in Central Iran microbial buildups » qui est finalement publié en 2021 dans Frontiers Earth Science (Baud et al. (2021).

5.9 – Une collaboration avec Francis Hirsch, Pablo Plasencia et Sylvain Richoz va permettre un réajustement de la stratigraphie du Trias moyen dans les Préalpes et dans tout le domaine briançonnais

Grâces aux progrès de la stratigraphie et de la paléontologie des conodontes du Trias et en me souvenant des échantillons favorables collectées dans le calcaire *Costatoria goldfussi* à 650 m au- dessus de la base de la séquence aux localités de Wiriehorn et Rothorn dans les Préalpes suisses, j'ai décidé de collecter des résidus après la dissolution du calcaire de ces échantillons. Le Dr Heinz Kozur, invité en 2002 par l'Institut de Géologie, les a examinés et a apparemment reconnu l'espèce *truempyi*, mais ne l'a jamais confirmé. Sylvain Richoz s'est occupé des conodontes extraits et ce n'est qu'en 2009 que j'ai pris contact avec le Dr Francis Hirsch, auteur de l'espèce, qui avait déménagé au Japon. Très intéressé, il a écrit au Dr Pablo Plasencia d'Espagne, qui étudiait des conodontes similaires (Plasencia et al, 2016, 2018). Celui-ci est venu à Lausanne pour examiner le matériel extrait et avec F. Hirsch a pu confirmer la détermination de *Sephardiella truempyi* (HIRSCH), et la courte durée confirmée de cette espèce à la base de l'étage Ladinien.

C'est pourquoi, avec eux, j'ai complètement révisé ma stratigraphie de la succession du Trias moyen des Préalpes suisses écrite en 1984 et nous avons publié ce nouveau point de vue sur l'ensemble du Trias moyen du Briançonnais dans les Alpes occidentales ainsi que sur la transgression marine du Ladinien précoce sur une partie de l'Europe de l'Ouest (Baud et al., 2016).

5.10 – Participation au nouveau projet 630 du PICG avec réunions au Cachemire, en Arménie et en Chine entre 2014 et 2018

Mon implication dans les projets triasiques du PICG s'est poursuivie avec le projet 630 dirigé par Zhong Kiang Chen, qui avait été nommé à l'Université des Géosciences de Wuhan (Chine). C'est avec le professeur Ghulam Bhat que j'ai saisi l'opportunité de proposer un congrès avec excursion sur le terrain au Cachemire et nous avons demandé au chef du projet 630, d'organiser avec nous cette première réunion annuelle du projet 630, en novembre 2014 (Fig. 35). Avec G. Bhat, j'ai rédigé le livret-guide de l'excursion à partir de mes données antérieures (Baud et al., 2014a), et aidé à organiser une excursion de 4 jours sur les principaux affleurements du Permien-Trias, puis le compte rendu (Baud et al., 2014b).

Figure 35 : Les participants à la réunion du PICG sur le terrain à Guryul Ravine, en novembre 2014, avec au milieu notre guide, Ghulam Bhat et à sa gauche, Zhong Kiang Chen .

Comme je l'ai fait avec le professeur Ghulam Bhat, j'ai proposé à la professeure Lilit Sahakyan d'accueillir un congrès avec excursion sur le terrain en Arménie. Avec l'agrément du chef du projet 630 du PICG, nous avons organisé cette deuxième réunion qui s'est tenue du 7 au 15 octobre 2017, avec 2 jours de conférence à Erevan sous la direction de Lilit Sahakyan, suivis de 6 jours sur le terrain dans l'Est de l'Arménie. C'est avec elle et toute notre équipe que nous avons rédigé le livret-guide de l'excursion (Sahakyan et al., 2017a), préparé un exposé et présenté nos résultats finaux dans un résumé (Baud et al., 2017), puis le compte rendu (Sahakyan et al., 2017b).

La réunion de clôture du PICG 630 s'est tenue du 22 au 24 mai 2018 à Wuhan, en Chine (Fig. 36a). J'ai présenté un exposé sur les résultats finaux des 10 dernières années des réunions des projets 630 et 572 du PICG et L. Sahakyan m'a inclus dans sa présentation de la réunion de terrain arménienne de 2017 (Sahakyan & Baud, 2018). J'ai reçu un prix honorifique du PICG (Fig. 36b). L'article que j'ai écrit sur ces résultats finaux a été publié dans le Journal of EarthScience (Baud et al., 2018).

5.11 – Les faciès récurrents de calcaires à ammonoïdes rouges au Permien moyen, au Permien récent et au Trias précoce, en Nouvelle-Zélande, à Timor, en Himalaya, en Oman et en Arménie et Iran, ouvre une nouvelle voie de recherche

Par nos recherches sur le terrain, nous avons accumulés des données sur les calcaires rouges à ammonoïdes et avons eu l'occasion de présenter des données partielles sur ceux du Permien moyen dans Baud et al. (1993) et dans Marcoux et Baud, (1996) et en particulier à Timor dans Baud & Marcoux, (1991), et également en Oman par Pillevuit et al. (1997), par Baud et al. (2001b), par Kozur et al. (2001a, 2001b), et par Richoz et al. (2013).

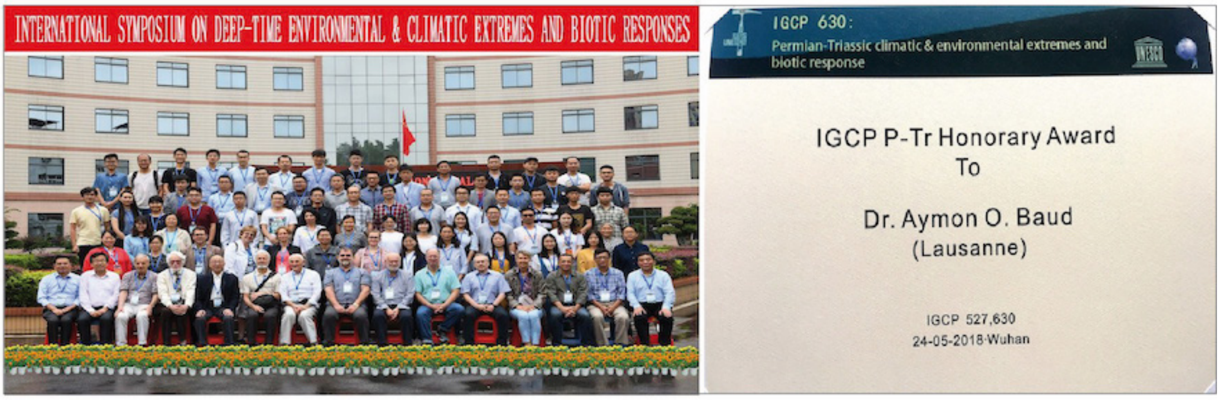

Figure 36 : a) Participants à la réunion de Wuhan en 2018, b) Prix honorifique du PICG.

Les faciès de calcaires rouges à ammonoïdes de la fin du Permien ont été illustré en Arménie dans Sahakian et al. (2017) et Arménie et Iran par Baud & Richoz, (2019).

Les faciès du Trias inférieur qui comprend les calcaires rouges à ammonoïdes décrits en Oman, dans l'Himalaya et à Timor, ont été présentés par l'auteur lors de la réunion jointe de GSC et GSA à Chengdu (Baud, 2013a).

Une approche sur ce faciès récurents à certaines périodes temporelles (Permien moyen, Permien récents et Olenekien) a été présentée à Pékin par Baud & Bucher (2019) et des travaux sont en cours pour publication.

5.12 – Une formation continue en géologie est proposée aux enseignants des lycées français et à l'école doctorale des étudiants en géologie lausannois, 2011-2016

Fin octobre 2011, j'ai à nouveau collaboré avec Thierry Juteau, pour offrir une excursion géologique dans la baie d'Antalya au sud de la Turquie (Fig. 37) et pour co-écrire le guide de terrain à l'attention des professeurs de lycée français intéressés (Juteau & Baud, 2011).

Figure 37 : a) Thierry Juteau explique les laves basaltiques aux enseignants français, b) La couverture du livret guide 2011.

Fin octobre 2014, j'ai conduit ces mêmes professeurs dans les Préalpes suisses et rédigé un livret-guide de terrain. Puis à fin octobre 2016, j'ai organisé et dirigé un voyage d'étude géologique de dix jours dans le sud et le nord d'Oman et rédigé le livret-guide (Baud, 2016).

Concernant la formation continue des doctorants en géologie lausannois, j'ai co-organisé en février 2016 avec le Prof. Stefan Schmalholz de l'Institut de Géologie de l'Université et l'aide du Prof. Jean-Pierre Burg de l'ETH Zurich, une école doctorale lausannoise de dix jours à travers les montagnes du nord d'Oman et les collines du Batain, et co-rédigé le guide de terrain (Burg & Baud, 2016).

5.13 – Dédicataire de deux genres et de trois espèces nouvelles qui portent mon patronyme et sont décrits par des collègues paléontologues

En paléontologie et en géobiologie, il est d'usage de nommer les organismes fossiles du nom de chercheurs connus pour ainsi les honorer. Deux genres (*Baudiella* et *Baudicrinus*) ainsi que trois noms d'espèces (*baudi*) d'organismes fossiles, qui comprennent un ostracode, deux foraminifères, un crinoïde et une ammonoïde m'ont été dédiés pour mes travaux de terrain et mes publications :

1. Demir et Ozkan-Altiner, spécialistes des foraminifères, dédient en 1998 le nouveau genre *Baudiella* au directeur du musée de Géologie de Lausanne pour sa contribution à l'étude du Permien-Trias téthysien (Altiner & Ozkan-Altiner, 1998).
2. Tatsuo Oji, spécialiste des Lys de Mer (Echinodermes), dédie en 2015 avec Richard Twitchett, le nouveau genre *Baudicrinus* à celui qui le premier a découvert un bloc calcaire d'âge Griesbachien dans le Wadi Wasit en Oman et l'espèce *krystsyni* à Leopold Krystyn qui l'a déterminé et confirmé (Oji & Twitchett, 2015).
3. Sylvie Crasquin, spécialiste des ostracodes, dédie en 1996 l'espèce *Polycope baudi* au directeur du musée de Géologie de Lausanne, en témoignage du succès de sa participation aux recherches géologique dans le Trias de la Dobrogea en Roumanie (Crasquin-Soleau, 1996).
4. Jérémie Gaillot et Daniel Vachard, spécialistes des foraminifères permiens, dédient en 2007*, l'espèce *Labioglobivalvulina baudi* à Aymon Baud de l'Université de Lausanne pour sa contribution à la recherche sur le Permien-Trias (Gaillot, J., & Vachard, D., 2007).
5. Thomas Bruehwiler, spécialiste des Ammonoïdes triasiques, dédie en 2012 l'espèce *Paranannites baudi* à l'auteur, en témoignage de ses recherches en Oman (Brühwiler et al., 2012).

5.14 – Contribution à l'histoire des sciences géologiques

Intéressé par la vie du premier professeur de sciences géologiques à l'Université de Lausanne, j'ai écrit un article historique sur « L'enseignement académique de la géologie à Lausanne de 1832 à 1906 : Eugène Renevier et les naturalistes géologues », (Fig. 38) dans le Bulletin de la Société vaudoise des sciences naturelles (Baud, 2019).

Intéressé également par l'histoire de la recherche et des découvertes des sections marines de la limite Permien-Trias dès la fin du 19ème siècle, j'ai écrit un article de 21 pages qui a été publié dans Albertiana (Baud, 2014) et qui illustre plus d'un siècle d'aventures et de controverses sur cette fameuse limite entre l'Ère Primaire et l'Ère Secondaire. Je l'avais d'abord présenté en 2013, lors d'un Congrès sur le Trias à l'Université des Géosciences de Wuhan en Chine (Baud, 2013).

D'autre part, comme participant aux recherches géologiques en Himalaya, j'ai présenté dans un poster un historique de l'équipe de recherche de Lausanne d'avant 1988, lors de la réunion du congrès HKT de 2018 à Lausanne (Baud, 2018c).

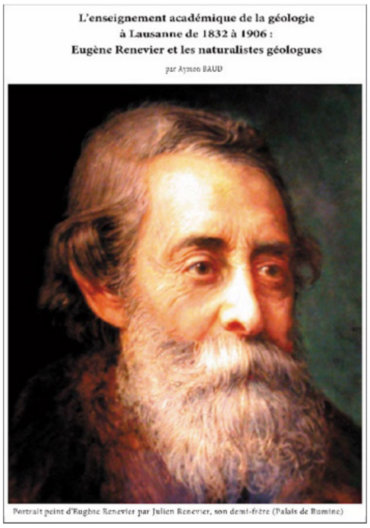

Figure 38 : Couverture de l'article sur Eugène Renevier.

5.15 – Hommages aux collègues décédés (Fig. 39)

Aux chapitres 4.3 et 4.4, j'ai présenté les hommages rendus à un ami et collègue Jean Marcoux.

Pendant près de 30 ans, j'ai partagé avec Edward Timothy Tozer (1928-2010) les aventures sur le terrain et les réunions de la Sous-commission de stratigraphie du Trias (SST), c'est pourquoi en 2012, j'ai écrit un hommage illustré sur sa carrière dans Albertiana, (Baud, 2012a).

En 2012, ayant appris le décès, à l'âge de 102 ans, du professeur émérite Augusto Gansser (1910-2012) de Zurich, que j'avais eu l'occasion, en 2002, d'interviewer sur ses découvertes en Himalaya, j'ai pris l'occasion d'écrire dans « Geosciences actuel », une courte notice biographique sur sa remarquable carrière (Baud, 2012b).

C'est en 2017 que j'ai appris le décès de mon collègue et ami Maurizio Gaetani (1940-2017), professeur émérite à Milano. C'est dans le périodique Albertiana que j'ai publié un hommage illustré sur toute sa carrière (Baud, 2018d).

C'est également en 2017 que j'ai été tristement surpris par le décès soudain le 3 novembre de Michaela Bernecker, Professeure à GuTech, l'Université allemande en Oman. Ayant travaillé et publié avec cette collègue très appréciée, j'ai écrit une biographie, avec le Dr Oliver Weidlich, dans le périodique Permophiles : « Michaela Bernecker (1963-2017), une enseignante, une scientifique et une amie remarquable » (Weidlich & Baud, 2019).

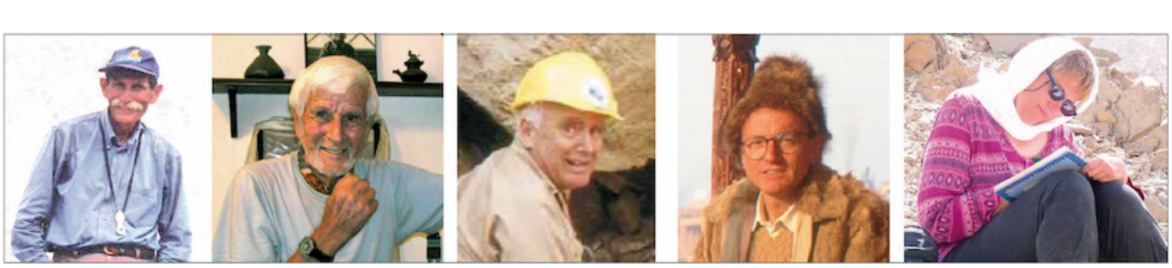

Figure 39 : de gauche à droite : Jean Marcoux, Augusto Gansser, Edward Timothy Tozer, Maurizio Gaetani and Michaela Bernecker.

Conclusions et remerciements : la fin du programme Sinergia (Paleo C4) et la conférence « Across the End Permian Great Extinction » du 30 août au 2 septembre 2023, à Lausanne

Au cours de ces 55 ans de recherche, je me suis passionné pour l'étude de cette période géologique ayant connu, d'une part, la plus grande extinction d'espèces sur la Terre et, d'autre part, la réapparition progressive des organismes complexes. Les découvertes d'enregistrement détaillés sur le terrain de ces événements nous ont permis de suivre de plus en plus précisément un envahissement algo-bactérien des mers peu profondes, la présence d'oasis de vie avec la renaissance d'organismes disparus il y a plus de 250 millions d'années. La recherche progresse dans ce domaine grâce à plusieurs éléments :

- des méthodes et instruments d'analyse de plus en plus sophistiqués ;
- de nombreuses observations sur le terrain dans le monde entier et des échanges fructueux entre collègues.

Nous parlons aujourd'hui beaucoup de crise climatique et de disparition d'espèces. Une meilleure compréhension des phénomènes du passé peut apporter de précieux éléments aux études actuelles.

La ligne de recherche sur les microbialites post-extinction, que nous avons mise en route en 1997 à Lausanne, a été appliquée avec succès en Chine du Sud et a permis d'ouvrir un nouveau concept d'accumulations spongio-microbiennes, aux sections étudiées du Trias inférieur dans le centre et le nord de l'Iran et en Arménie, avec là, cette découverte de constructions géantes de microbialites à éponge (cf. chap.5.7). J'ai pu en faire part durant la conférence sur les microbialites organisée par le

comité d'organisation Suisse du 11 au 13 octobre 2023 à Leysin (Baud 2023).

L'étude sur le terrain de la région de Batain au sud-est d'Oman avec l'équipe de recherche d'Hugo Bucher a conduit à la découverte de nombreux blocs riches en fossiles et de récifs inconnus du Trias inférieur, ce qui a considérablement élargi la ligne de recherche sur la récupération rapide des métazoaires au cours du Trias basal.

L'étude paléontologique des échantillons collectés et rassemblés à l'Institut et au Musée paléontologiques de Zurich, qui a été réalisée par les doctorants, les assistants et les professeurs, offre une vision plus précise de l'âge stratigraphique et facilite grandement la corrélation entre les bassins permiens et triasiques éloignés.

Mon implication au programme de recherche Sinergia des Universités de Zurich, Lausanne et Genève m'a amené à collaborer avec les professeurs Hugo Bucher, Torsten Vennemann et leurs étudiants doctorants et maintenant Docteurs ès Sciences : Morgane Brosse, Marc Leu, Zoneibe Luz Franziska Blattmann et Oluwasser Edward ainsi qu'avec le Dr. Christian Vérard de l'Université de Genève. Les thèses et publications issues feront dates dans l'ensemble des travaux sur le Permien-Trias

La mise à disposition des échantillons collectés pour des études géochimiques réalisées par les doctorants dans les laboratoires de l'UNIL, sous la direction des professeurs Torsten Vennenann et Thierry Adatte, a ouvert de nouvelles approches sur les paléoenvironnements du Permien-Trias comme les travaux de toute l'équipe Sinergia l'ont montré.

Avec toutes et tous nous avons eu des échanges très fructueux qui ont abouti à des présentations communes dans de nombreux congrès, à des chapitres de thèses et à des publications. Merci à vous tous, chères et chers collègues, pour ce partage.

Pour la Conférence à Lausanne sur le Permien-Trias, j'ai bénéficié dès le début de l'année 2023 de l'aide inestimable du comité d'organisation avec les professeurs de l'Institut des Sciences de la Terre de l'Université de Lausanne, Michel Jaboyedoff, Jean-Luc Epard, Torsten Vennenann et Thierry Adatte

sous la présidence de Allison Daley, professeure et directrice de l'Institut. Un comité scientifique avait également été constitué, comprenant les professeur(e)s Benoît Beauchamp (University of Calgary), Hugo Bucher (University of Zurich), Charles Henderson (University of Calgary), Nicolas Goudemand (ENS Lyon), Jonathan Payne (University of Stanford), Sara Pruss (Smith College, Northampton, MA). Ces deux comités ont permis une tenue exemplaire de la conférence «Across the End Permian "Great Extinction" du 30 août au 2 septembre à Lausanne. Qu'ils en soient toutes et tous remerciés chaleureusement de même que tous ceux qui ont œuvrés au bon déroulement de la conférence et qui sont cités nommément dans le compte-rendu qui figure en page x de ce Mémoire de Géologie.

Ma reconnaissance va également à tous les participants de la Conférence ainsi que tous ceux qui m'ont généreusement associés à leur présentation comme co-auteur ou dans leurs hommages.

Pour ce Mémoire, je remercie particulièrement Madame Catherine Schlegel Rey, éditrice de ce volume spécial, et Luca Spallitta, pour la mise en forme sur InDesign. Le texte anglais a été revu par Scholars Editing et le texte français corrigé par Monique Baud, qui m'a aussi encouragé dans mes recherches durant toutes ces années et m'a accompagné lors de plusieurs expéditions, merci encore.

La bibliographie générale se trouve à la suite du texte anglais.

Fifty-five years of continuous Permian-Triassic field research and corresponding publications by Aymon Baud, in collaboration with the Geological Institute of Lausanne University, Switzerland, 1968-2023

Aymon Baud

Associate researcher, Earth Science Institute, Geoscience Faculty, Lausanne University, Switzerland

This illustrated text has been prepared for the conference "Across the End Permian 'Great Extinction': from Permian-Triassic Field Studies to Scientific Results" held August 30- September 2, 2023, at University of Lausanne, Switzerland. This conference is to reflect, celebrate, and pay tribute to Dr. Aymon Baud', fifty years of continuous Permian-Triassic field research and corresponding publications produced in part with the Swiss National Science Foundation (FNSRS) and other State Foundations help, and in association with the Geological Institute and Museum at Lausanne University, Switzerland. It shows 5 periods with each subdivided into 8 to 12 chapters.

1 – The first period from 1968 to 1984

This first section focuses on 17 years of PhD study, extremely beneficial collaboration with colleagues and professors, publishing of field and laboratory research, and successful doctoral presentations.

1.1 – PhD study on Middle Triassic carbonate succession from Prealps to western Alps, 1968-1984

On April 22, 1968, I received my Master diploma in Geology, and I decided to begin my PhD studies on the sedimentology and stratigraphy of the Middle Triassic carbonate succession of the internal Swiss Pre-Alps domain.

With my appointment as graduate assistant of Professor Héli Badoux, I began my studies at the Saint-Triphon quarries in the Swiss Rhône Valley and continued the work of Professor of Geology François Ellenberger (La Sorbonne, Paris), who was the first to correlate the Triassic succession of the Swiss Prealps with the Triassic succession of the internal part of the Western Alps known as the "Briançonnais".

I first got in touch with Dr. Francis Hirsch, a paleontologist from Zurich University, and together we sampled and logged the Anisian flinty limestones. Through dissolution, he discovered conodonts. My first co- authored publication resulted from this (Baud et al., 1968).

I was invited to work as an assistant at the Lausanne Geology Museum in 1972, and I was named the museum's curator in 1974. After conducting field research, Dr. Henri Masson and I worked together to find what appears to be Switzerland's oldest vertebrate fossil in 1974 (Baud, 1975). Our work then continued on paleotectonics (Baud & Masson, 1975, 1976 ; Baud et al., 1977). My next papers were on Decapoda (Baud, 1976) and on my view on the Triassic stratigraphic scale (Baud, 1977).

On the Permian-Triassic boundary, a first collaboration with my colleagues Demir Altiner, Jean Guex and Gérard Stampfli led to correlations in several Middle Eastern localities and the discovery of stromatolites at the base of the Triassic (Altiner et al., 1980). This discovery is developed in chap. 3.8.

For clay study in my Triassic carbonate, I started a collaboration with Professor Bernard Kubler from Neuchâtel University, and his short course on clay mineralogy greatly aided the mineralogical study of clay content in Anisian limestones and with illite crystallinity, the anchi-metamorphism zones of the Prealps Triassic (Baud, 1984).

I pursued numerous collaborations up to 1983, which gave me the opportunity to contribute to the 22 articles that were published as well as to write the 300 pages of my thesis manuscript (Baud, 1984, 1987) while continuing, during summers, to map the Triassic succession on the Niesen, Adelboden (Furrer et al., 1993) and Zweissimen maps of the Swiss geological Atlas 1 :25,000. In Dec. 1984, I defended my PhD work with an appendix of these 22 published articles on "The Natural History of the Saint-Triphon limestone (Anisian, middle Triassic, Swiss Prealps)", and obtain the Jury congratulations.

1.2 – Collaboration with Professor Paul Brönimann of the University of Geneva and his Assistant Dr. Louisette Zaninetti

A fruitful collaboration with Professor Paul Brönimann of the University of Geneva and his PhD assistant Louisette Zaninetti, who specializes in Triassic foramininifera, was launched when I began mapping, logging, and sampling numerous Anisian outcrops in the Prealps. I then began studying the thin sections and discovered a wealth of foraminifera, microfossils that had never been described in these regions. The results were the publication of six paleontological papers (foraminifera and coprolites) on Prealps Anisian limestones from 1971 to 1974 (Baud et al., 1971, 1972, 1974 ; Broennimann et al., 1972 ; Zaninetti et al., 1972a, b).

1.3 – Field works out of Europe, the start of Permian study in Iran and Pakistan, 1972-1975

I had the good fortune to continue working closely with Paul Brönimann and Louisette Zaninetti, and in October 1972 and October 1974, they invited me to conduct fieldwork on Permian-Triassic strata in Iran (Baud et al., 1972, 1974). Our field research success in March 1975 focused on the Pakistan Salt- and Trans-Indus Ranges Permian-Triassic (Fig. 1). Key stratigraphic sections were well sampled and were initially kept at the Geneva Paleontological Institute before being transported to the Lausanne Geological Museum.

1.4 – Collaboration with Dr. Joséphine Mégard-Galli, assistant to Prof. Ellenberger from Paris-Sorbonne

In 1972, J. Mégard-Galli and I began another productive collaboration in which we jointly investigated some of the outstanding Triassic outcrops in the Western Alps Briançonnais region as well as Middle Triassic carbonate on Corsica and Sardinia (Baud et al.,1977). This led to extremely precise correlations of the new established Saint-Triphon Formation and the units surrounding it, of Lower and Middle Triassic age, from central Switzerland across the western Alps to the Mediterranean.

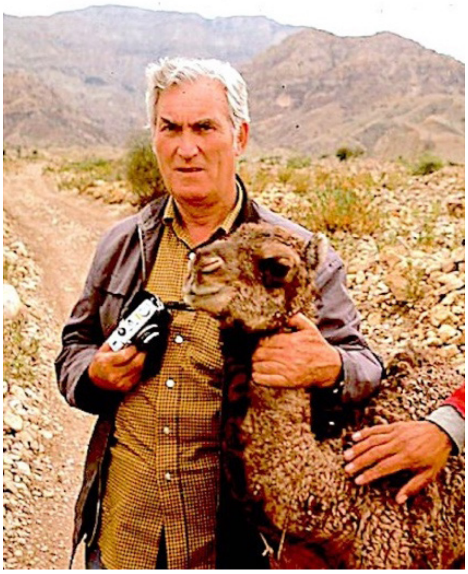

Figure 1 : Professeur Brönimann at Narmia Nala (Pakistan)

We can describe these correlations and provide new methods based on the cyclicity of carbonate sedimentation and the most important recently identified transgressive-regressive sequences thanks to several presentations at international conferences and several publications (Baud & Mégard-Galli, 1975, 1977 ; Mégard-Galli & Baud, 1977). With her, the stratigraphy and sedimentology of the Briançonnais Triassic underwent significant advancements, and she was instrumental in the development of a synthesis of the Triassic of the Western Alps that was published in the 1994 Mémoires du BRGM (Mégard-Galli et al. 1984).

1.5 – Himalaya-Ladakh field studies : started first with the Lausanne Geological Institute, followed by cooperation with Grenoble and Milano colleagues, 1977 to 1983

In early 1979, I initiated a Lausanne Himalayan research group. With Prof.A. Escher, H. Masson and A. Steck, I co-organized the first eastern Zanskar geotraverse Hemis-Padum in 1979 (Fig. 3) and results were published in Baud et al., 1982, 1983.

We organized an expedition to conduct in-depth stratigraphic sections and tectonic investigations in central Zanskar, N and E of the Spongtang ophiolite Klippe, in 1981 with Prof. G. Mascle from Grenoble) and Dr. E. Garzanti from Milano (Baud et al., 1985 ; Garzanti et al, 1987).

I took part in a SE-NW geotraverse from Darcha (Lahul) to Thongde (Zanskar) in 1983 at Prof. M. Gaetani's (Milan) invitation, passing through Sarchu, Phirtse-La, and Phugtal (Baud et al., 1984).

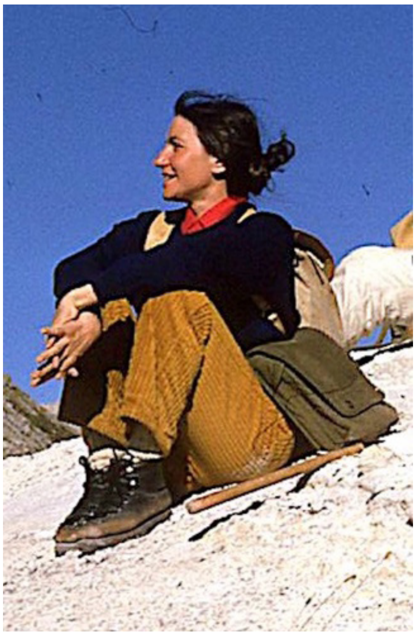

Figure 2 : Dr. Joséphine Mégard-Galli in the field, August 1970.

Figure 3 : Crossing Lungtung River (Ladakh, Himalaya), 4600m high, during Hemis-Padum geotraverse.

The main results obtained in collaboration with the above-mentioned teams can be summarized as follows :

1. The discovery and definition of large-scale SW vergent nappes structure in the Zanskar sedimentary belt (Tethys Himalaya).

Despite fierce opposition and disagreements regarding the nappe's idea from geologists with an autochthonous mindset, extensive fieldwork and mapping have recently largely validated the theory's structure.

2. A geological profile through E Zanskar, from Hemis to Padum.
3. Detailed stratigraphic sections of late Cretaceous and early Tertiary sediments of central Zanskar with the geodynamic interpretation of sedimentary record of the northward flight of India.

The rest of this cooperation is described in chapter 2.9.

1.6 – Continuing geological and stratigraphical education provided by international Conferences, 1971-1984

I chose to participate in the international Congress so that I could stay up to date on the most recent developments in sedimentology and stratigraphy. I participated in a Triassic excursion to the Northern Limestone Alps of Bavaria in 1971, immediately after the 8th International Sedimentological Congress in Heidelberg (Dachstein, Hallstadt, Hauptdolomit, Kössen beds). In 1971, I received a good training in Triassic stratigraphy and continued research outside of the Western Alps.

I attended the 9th and 11th International Sedimentological Congresses in Nice in 1975 (Baud, 1975) and Hamilton in 1982 (Baud, 1982), respectively, and I paid a visit to Dr E.T. Tozer in Ottawa (Fig. 4).

Figure 4 : Visit to E.T. Tozer and his wife, left, in Ottawa, August 1982.

I was given the chance to attend the 27th International Geological Congress (IGC) in Moscow in August 1984, as well as the official meeting of the Sub-Commission on Triassic stratigraphy (STS), where I was appointed as the new Vice-Chairman.

Two successful fieldtrips on Permian-Triassic boundary of new areas, the Setorym Creek in Verkoyansk Mountains (East Siberia) and the Vedi and Sovetachen sections in Transcaucasus (Armenia) were organized before and after this 1984 IGC in Moscow. It was a unique opportunity for participants to collect samples of these remote sections. This has enriched the museum's collections for future research, and which we describe in chapters 2.4, 5.7, 5.8 and 5.10.

1.7 – Visit of new geological sections and sampling provided by the Triassic projects of the International Geological Correlation Program (IGCP) of UNESCO

My involvement in IGCP Projects 4 and 106 began with field workshops in Bergamo (1979), Bratislava (1980), Sarajevo (1981), and a final meeting in Vienna (1982). The 1979 gathering was organized by Isabella Premoli Silva and Maurizio Gaetani in honor of R. Assereto and J. Pisa, and it was held in the renowned Bergamo castle (Italy), where I gave a talk (Fig. 5a). In 1980, the IGCP Project 4 on the Triassic realm organized a field meeting in Bratislava (Slovaquia) with excursion in eastern part of the country and in 1981, the IGCP Projects 4 and 106 organized a field meeting in Sarajevo (Fig. 5b).

Figure 5 : a) I give a talk in Bergamo castle, 1979, b) Picture of Anisian red ammonoid limestone (Han Bulog) near Sarajevo, 1981.

The opportunity to participate in the first Chinese IGCP Project 203, "Permo-Triassic events in the Eastern Tethys", proposed and directed by Prof. Zun-Yi Yang, came about in March 1984. It started with a successful conference in Beijing, followed by the fieldtrip to Shangsi section (see chap. 2.2).

1.8 – New collaboration with Professor Dimitri Papanikolaou of the University of Athens

At the invitation of Professor Dimitri Papanikolaou of the University of Athens, I started research in Greece in 1980 and 1981, sampling new Permian-Triassic sections from the islands of Salamis, Hydra, Chios and Aegina, as well as the Permian of Attica, Eastern Greece (Baud & Papanikolaou, 1981). Our results were presented in two meetings as shown below. During the following periods, cooperation with him and new research teams continued in Greece (see chap. 2.3).

2 – The second period : 1985-1992

The second period from 1985 to 1992 presents a different narrative : I embarked on four research programs. I pursued a multi-collaboration on Permian-Triassic study and new lines of research emerged.

In 1985, I was requested to teach carbonate sedimentological classes at the Geological Institute after taking over as interim director of the Geological Museum from the departing director, who had taken a sabbatical and in 1986, I was promoted to Director of the Lausanne Geological Museum.

2.1 – First Geotraverse, the Western Tibet, 1985

In 1985, I took a sabbatical to participate in the first authorized expedition to Western Tibet. This region of high plateau and deep valleys, which had always been closed to Westerners, gave me the opportunity to participate in a unique geo-traverse from the High Himalayas to the Kun Lun range, and to make geological observations before joining the plains of Central Asia along the Silk Road.

After this, I spoke at the Istanbul meeting at Prof. Celâl Sengör's invitation and I also published in Baud, (1985,1989a ; Baud et al., 1994), detailing my observations made in the Kailas region and along the Sutlej-Yarkand geotraverse.

2.2 – The Triassic projects of the International Geological Correlation Program (IGCP) of UNESCO

My involvement in IGCP project continued with field workshops in Istanbul and Antalya (Turkey, 1986), in Beijing and Nanjing (China, 1987), in Salt Range (Pakistan 1987) followed by a Kashmir trip (India) and finally in Vladivostok (E Russia, 1992).

In 1986, I co-organized the meeting of the Sub-Commission on Triassic stratigraphy (STS) (Fig. 6) and a field conference on the Permian and Permian-Triassic boundary in Istanbul, Turkey, as part of IGCP 203 with Jean Marcoux and Celâl Sengör.

Figure 6 : Meeting of the officiers of the Sub-Commission on Triassic stratigraphy (STS), with Celâl Sengör and Bill Holser in Istanbul, July 1986.

Jean Marcoux invited Leopold Krystyn and me on a trip to the Antalya nappes, west of Kemer (SW Turkey). J. Marcoux has studied the Permian and Triassic in this area for a long time (Marcoux et al., 1986 ; Marcoux & Baud, 1988).

I actively took part in two field workshops for the IGCP project 199 in 1997 :

- The first workshop took place in March and was led by Prof. Sun Shu of the Academia Sinica. We met in Beijing and Nanjing and had the chance to collect samples from the Changhxingian stratotype in the Meishan area, from the P/Tr boundary clay, and from the mixed beds (1 to 3) of the earliest Triassic (Boclet et al., 1988).
- The second was held in Pakistan's Salt Ranges in December to work on a crucial PT portion. I participated and gathered late Permian samples with my post-doctoral student C. Jenny.

Profs. M. Gaetani, J. Marcoux, and E.T. Tozer also participated. Together, we made the decision to travel to Kashmir (India) in order to conduct research at the well-known Guryul Ravine Permian-Triassic section and to gather samples for later study (Chap. 3.4, 5.4 and 5.10.

J.M. Dickins oversaw the Project 272, “Late Paleozoic and Early Mesozoic Circum-Pacific Bio-Geological Events”, which followed the IGCP Project 203. Together, we assisted Profs. Yuri Zakharov and Galina Kotlyar (Fig. 7a) in September 1992, in organizing the first Permian-Triassic conference and field workshop in Vladivostok, Russia. It was sponsored by IGCP Project 272 and supported by STS. As co-organizers, we had the chance to travel to four major Permian-Triassic parts of this Far Eastern Russian region that were never accessible to scientists from western countries.

A published book was printed in 1997 (Baud et al., editors, 1997) and a correlation paper in Zakharov et al. (2005), see next in chap. 4.6.

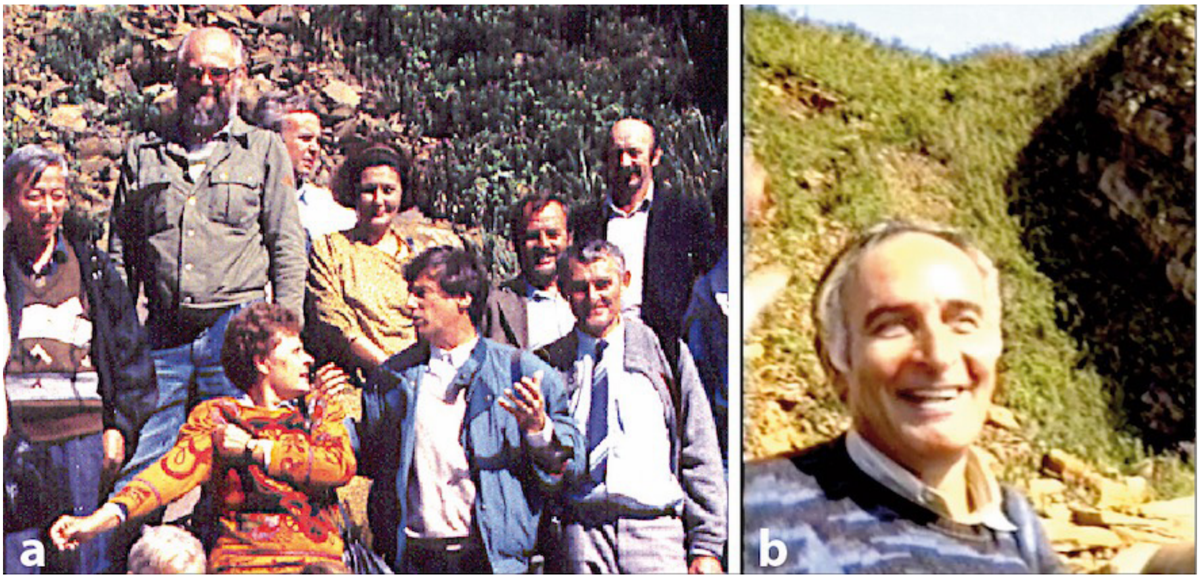

Figure 7 : The Vladivostok fieldtrip, 1992, a) Discussion between the author and G. Kotlyar in the front, Y. Zacharov on the right and H. Kozur on the back high, b) Guiseppe Cassinis say good bye !

2.3 – Micropaleontological studies of the Permian Tethys

I was granted permission to submit research proposals to the Swiss National Foundations (FNRS) for micropaleontological investigations of the Permian Tethys. In 1987, I get financial support for a post-doc assistant for Dr. Catherine Jenny, a specialist in Permian foraminifera investigations. Between 1987 and 1989, we began studying the Permian in Greece, at Professor Dimitri Papanikolaou's invitation. We made fieldworks on Permian of the islands of Chios, Aegina and new sections from Hydra and published four papers (Baud et al., 1990, 1991 ; Baud & Jenny, 1991 ; Jenny-Deshusses & Baud, 1989). In 1990, we worked along with K. Grant and M. Nestell to publish an achievement on the Permian study of Hydra (Grant et al., 1991) and later the Jenny's works (Jenny et al., 2004, 2009).

2.4 – From 1986 begins a new line of research : the Carbon isotope stratigraphy in collaboration with Profs William Holser (Eugen, USA) and Mordekai Magaritz (Rehovot, Israel)

I began working with Professors William Holser (Eugen, Oregon, USA) and Mordekai Magaritz (Rehovot, Israel), and I sent sample collections from important PTB sections between the S Alps, Turkey (Fig. 8) up to S China that I had examined and kept at the Lausanne Geological Museum to the Magaritz C isotope laboratory. We were able to build a new database on stable Carbone Isotope, to prepare talks for upcoming Permian-Triassic meetings and a key paper on Permian-Triassic C isotope stratigraphy (Baud et al., 1986 : Baud & Magaritz, 1988, 1989 ; Magaritz et al. 1988).

Boosted by IGC Project 199 with new sampling opportunities on key Permian and Triassic successions, we published, after analysis, twelve well dated sections with C isotope curve from bulk rock marine carbonate samples, showing in 1989, for the first time, the global shift at the boundary : a new tool for marine Permian-Triassic boundary correlation was open and 2 main PTB candidate sections, Meishan and Shangsi, were discussed and illustrated (Baud et al., 1989). The results exceeded our expectations and following an initial publication in the periodical "Nature", our article had a considerable impact and got high citation index.

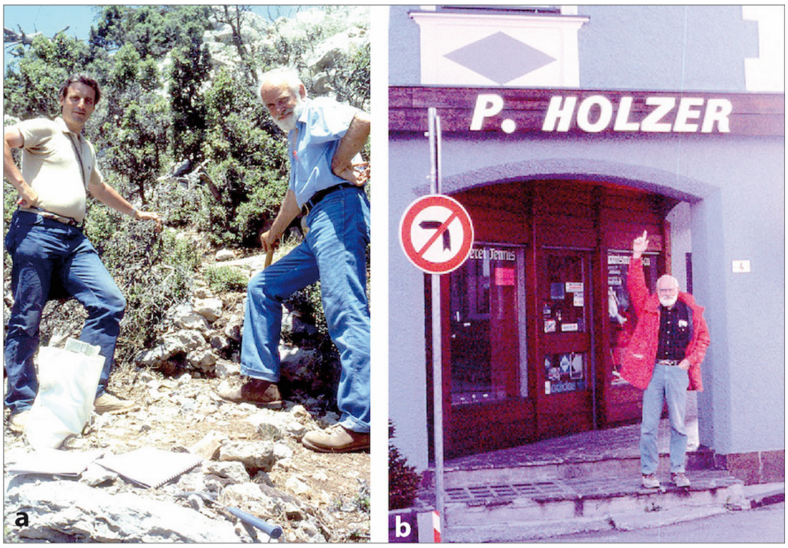

Figure 8 : Bill Holser , a) with the author on Curuck Dagh, (Turkey) outcrop, 1986, b) in front of a shop showing a "Holzer" name !

2.5 – From Vice-chairman to Chairman of the Sub-Commission on Triassic stratigraphy (STS)

I was elected as the new Chairman of the STS in 1989 during the International Geological Congress, which was held in Washington, D.C., after serving as vice-Chairman in 1984. I also received approval from the international committee on stratigraphy.

My duty was to organize a Triassic Congress and to promote Stage name and Stage boundary agreement. I proposed in 1991 that a Triassic Stratigraphic Symposium be held in Lausanne at the request of the Sub-Commission members. In October 1991, with assistance from the Museum's staff, the Geological Institute, and the University of Lausanne, I led this Symposium with the assistance of Jean Guex (Lausanne), Maurizio Gaetani (Milano), Jean Marcoux (Paris), Hans Rieber (Zurich), and others.

About fifty professionals from 22 different nations attended this symposium over the course of four days (Baud, ed., 1991). This was followed by a one-day local field trip to the Anisian Saint Triphon quarries and the Norian salt mine of Bex (Baud & Meisser, 1991). Following favorable voting, we decided to propose two Stages for the Lower Triassic period with the STS : Induan and Olenekian. Collectively, we participated in the editorial committee of the 1994 proceeding (Guex & Baud, 1994). Next is Chap. 3.6.

2.6 – Participation in International Geological Congress and Fieldtrip

I took part in the 1989 International Geological Congress that was held in Washington, D.C. I gave a talk there (Baud, 1989b) and took opportunity to participate in the West Texas Congress field trip and reconnected with Professor Norman Newell of the New York Natural History Museum (Fig 9).

Figure 9 : Norman Newell and the author : a) at the S China fieldtrip, 1984, b) at the West Texas fieldtrip, 1989.

In 1991, I took the opportunity to participate in the International Congress on Permian System of the World in Perm (Russia). I gave a talk on the Permian succession in Greece (Baud & Jenny, 1991) and participated in the Permian of Ural's fieldtrip. It was an opportunity to reunite with colleagues Professors Galina Kotlyar from St. Petersburg and Yuri Zakarov from Vladivostok after the 1984 International Geological Congress in Moscow and plan along with them for the 1992 Permian-Triassic International Field Meeting in Vladivostok (see 2.1- IGCP meeting).

In August 1992, while serving as the Chairman of the STS, I attended the International Geological Congress (IGC) in Kyoto and spoke at the Gansser Symposium about the "Neotethys opening in Oman" (Baud, 1992). Professor Augusto Gansser is being honored up front. After that, I traveled to Central Japan for a Permian-outcrops field trip and then joined the Vladivostok meeting (p. 48).

2.7 – The international research program «Tethys» with field works in Oman, Timor and W Texas

The year 1989 is the beginning of my involvement in a major international research program called "Groupement Scientifique Tethys" and the start of financially supported geological research in Oman, in Timor and in W Texas. With Prof. Jean Marcoux and Post-doc assistant Sylvie Crasquin, we established Permian-Triassic working groups. Several working meetings were held in 1989 and 1990, at the Museum in Lausanne and in Paris, respectively.

As part of this "Tethys" international research programs, Permian and Triassic samples were collected from 1989 (Baud et al., 1989) to 1992 in Oman and in 1991 from the island of Timor, Indonesia (Baud & Marcoux, 1991). To complete our data, we organized with Jean Marcoux field research on the Permian Basin of the W Texas (Baud & Marcoux, 1989).

With Gérard Stampfli, a new professor of geodynamics appointed to Lausanne, we took up the history of the Tethyan margins in space ad time, and published it, under his leadership (Stampfli et al., 1991). We also resumed work on samples from eastern Iran received from our Austrian colleague Anton Ruttner (Baud, Brandner et al., 1991, Baud, Stampfli et al., 1991).

Jean Marcoux oversaw the Triassic paleogeographical and paleoenvironmental maps working group (Anisian and Norian maps) and helped me greatly on my charge of the Permian, Murgabian map.

Results and paleogeographic maps of the “Tethys” international research programs were presented at a final meeting in 1992. The 3 maps with accompanying notes on Permian and Triassic environments produced by our research group (Baud et al., 1993; Marcoux et al., 1993a, 1993b) are part of large book printed at the end of 1992 with Dercourt et al. as editors. Permian-Triassic paleoenvironments were published also in Marcoux & Baud, (1996).

2.8 – Field works in Canadian High Arctic Lower Triassic stratotypes, via invitation by Prof. Benoit Beauchamp, July 1992

My first encounter with Prof. Benoit Beauchamp from Calgary University (Canada) took place at the Perm Conference in 1991, and he gave me two targets:

1. my participation,
2. my participation in Permian-Triassic field research in the Canadian High Arctic with support from the Geological Survey of Canada.

I accepted it with enthusiasm. With his formal invitation, at end of June 1992, I was able to join the Benoit Beauchamp field expedition in the Canadian High Arctic (Fig. 10), on Ellesmere and Axel Heiberg islands under the Geological Survey of Canada support. Profiles of Late Permian and Early Triassic type sections were studied and rocks samples from the Permian-Triassic transition was sent to the Lausanne Museum for analysis.

2.9 – Himalaya research group with Profs Henri Masson, Gérard Stampfli and Albrecht Steck

With our local research group on Himalaya with Profs H. Masson, G. Stampfli and A. Steck, we took the opportunity to organize the fourth Himalayan-Karakoram-Tibet workshop in Lausanne and organized a public exhibition on our Geological work and discoveries in Ladakh Himalaya in 1988.

I worked as the editor of the Conference Proceedings (Baud, 1989c) and published a response to G. Fuchs (Baud 1989d).

Figure 10: a) Otto Fiord camp on Ellesmere Island, July 1992, b) Some participants with B. Beauchamp 3rd from left.

3 – The third period: 1993-2003

Three new study programs were initiated during the third phase, which ran from 1993 to 2003, and two new research lines were initiated, up until my retirement from the Geological Museum.

3.1 – The Pangea Project of the Commission on Global Sedimentary Geology(C-GSG) : 1992-2003

I was requested to co-produce Pangea charts and was given the opportunity to present an overview of European research on the disappeared ocean Tethys at the University of Kansas at Lawrence for the inaugural meeting of the international scientific initiative Pangea. The project Pangea was published in GSA Special paper 288 as shown by the "Introduction" below.

It was then decided that Project Pangea would focus on the most recent time of supercontinent accretion and dispersal, i.e., from the Carboniferous to the Jurassic, when continents merged toward a geoid low, and much of Pangea's climate appeared to be disposed in an icehouse mode (Baud, 1992 ; Ross et al., 1992). This project was part of the IUGS Program on Global Sedimentary Geology (P-GSG) chaired by B. Beauchamp and I collaborated with him for this Pangea project. Meetings were often associated with international Congress. In Aug. 15-19, 1993, the Pangea project held the "Tethys evolution during Pangea time Conference" in Calgary, Canada, organized by B. Beauchamp and A. Embry. I was asked to be responsible for one of the conferences themes, and I organized and led one of the sessions. I also gave two lectures (Baud, 1993a, b) and contributed to the presentation of four posters (Baud et al., 1993 ; Marcoux & Baud, 1993 ; Marcoux et al. 1993b, d).

The following Pangea summit took place as IGCP Project 359 in Guiyang, China, from August 28 to August 31, 1994, during the International Symposium on Permian (ISP). I participated in the work of the international sub-commission on Permian stratigraphy and presented a paper at the Guyang Congress (Fig. 11), as a member of the scientific committee (Baud, 1994).

A Pangea meeting took place in Wuhan, Hubei, China, from March 9–11, 1999. The proceedings of the Conference with 14 papers (175 pages) were published as a University of Wuhan Special Publication. I chaired a session and gave a talk on our results with Viorel Atudorei on PTB in Oman (Baud et al., 1999).

Figure 11 : Group photo of the Guyang Permian Symposium, 1994.

B. Beauchamp organized the event in Calgary, Alberta, in August 1999 as part of the International Congress on Carboniferous and Permian Stratigraphy. Our research group contributed three abstracts to a special Pangea session on the Permian-Triassic transition (Baud, 1999 ; Beauchamp et al., 1999). At that time, I visited the Last Chance Saloon (Fig. 12).

Figure 12 : At the Last Chance Saloon, Bad Land, August 1999, Canada.

In 2001, the final Pangea meeting was held in Oman. With the coordination of research groups, I got the opportunity to include an Oman Pangea Symposium and field meetings in the International Conference on the Geology of Oman, organized by the Oman Ministry of Commerce and Industry. The 2-day Pangea Symposium started on January 14, in which 18 oral communications and 5 posters were presented. A field excursion was organized before the Conference and one four-day Post-Conference Excursion (Baud, Béchennec et al., 2001a, b). To prepare the three highly detailed field guidebooks, there were ten of us working together. The proceedings were published in a special issue of Palaeogeography, Palaeoclimatology, Palaeoecology (PPP -Baud et al., editors, 2003), and we wrote a Symposium report (Baud et al., 2001c) and participate at four papers (Baud & Beauchamp, 2003 ; Kozur et al., 2001a, b) and with Krystyn et al. (2003) a new line of research started (see chap. 3.9).

3.2 – The Peri-Tethys International Geological program 1993-1999

Following the "Tethys" international research program, a new International Geological program called Peri-Tethys was launched. At the same time, there was a new IGCP Project 343, "Correlation of epicratonic Tethyan basins".

We established an IGCP research group on the Permian-Triassic boundary crisis while working on the Peri-Tethys program with Jean Marcoux and Sylvie Crasquin. Financial funding was given to my proposal for field research and sampling in the Dobrogea region of Romania (Project Péritethys 95-32). I delivered a talk and oversaw a session during the second gathering, which was held in Bucharest in September 1993 (Baud, 1993). A collaborative study on the Lower Triassic of the Dobrogea that we published in 1997 has become a benchmark (Baud, editor, 1997 ; Baud et al., 1997).

A new collaboration started with Dr. Lucia Angiolini from Milano University who came to our Lausanne Geological Museum for Oman Permian brachiopod study collected by our post-doctoral student Alain Pillevuit. In January 1995, we were invited to participate in an international Peri-Tethys expedition that was carried out in the Sultanate of Oman for a better understanding of the stratigraphy, paleontology, sedimentology and paleoecology of the Permian succession of the Huqf area. During this expedition, a large collection of brachiopods were sampled along two stratigraphic sections at Saiwan and Wadi Haushi, studied and published by Lucia Angiolini with all our research team (Angiolini et al., 1995, 1997).

During the summer of 1996, a field campaign in the Ukrainian Crimean Peninsula was planned as part of the Peri-Tethys initiative. I traveled to Simferopol, Ukraine, with Jean Marcoux to conduct fieldwork on the Permian and Triassic blocs in Crimea under the direction of Professor Galina Kotlyar. After examination of the thin sections in Galina Kotlyar's laboratory (Fig. 13), our study led to the dating of the exotic blocks from this Ukrainian territory, their comparison with the exotic blocks from Kürée (northern Turkey) and the full publication of the results, issued in Kotlyar et al. (1999).

3.3 – Return to Canadian High Arctic Lower Triassic stratotypes, with new discoveries, 1994

Invited again by Benoit Beauchamp, I got the opportunity to work with Charles Henderson (Fig. 13). Together, we sampled for conodont studies the High Arctic localities with Otoceras on Axel Heiberg and Ellesmere Islands, to solve the controversy regarding the lower *Otoceas* zone correlation. The results were published in the Proceedings of the Beijing IGC 1996 (Henderson and Baud, 1997): overlying Changxing conodonts, the *parvus* conodont species appears in the middle of the upper *Otoceras* zone (*Otoceras boreale*).

Figure 13 : Invitation to Kotlyar's home after laboratory work with M. and G. Nestell in the ground, 1986.

Later, in 1999, Amalia Spina, a PhD student from Perrugia (Italy), received a UNESCO grant to conduct a palynological study of the Permian-Triassic arctic collection in our Lausanne Geological Museum. She then presented this new perspective on palynological evolution at the Permian-Triassic transition in the Sverdup basin along with S. Cirilli and our research team (Cirilli et al., 2001). In his analysis of the formation of Late Permian biogenic chert rocks in Arctic regions and with climatic change, Benoit Beauchamp linked me to his disappearance at the Permian-Triassic transition. Following presentation at Pangea Symposium 2001, we published it (Beauchamp & Baud, 2002), and this paper quickly got high citation index.

3.4 – Swiss National Foundation's projects on Triassic Carbon isotope studies, Research undertaken with Viorel Atudorei (1994-1999)

With the appointment of Zachary Sharp as new professor in Lausanne, a new C isotope laboratory came into operation and research programs could be submitted. To deepen the successful chemo-stratigraphic tool developed with Profs W. Holser and Magaritz, I proposed in 1993, a research project on Triassic C isotope studies at the Swiss National Foundations (SNF=FNRS) and got financial support in 1994 for Viorel Atudorei from Romania. With him, an important collection of Triassic rocks from the Dobrogea (Romania) was assembled and studied in detail in 1994, and also during the1995 Peri-Tethys field meeting (Fig. 14).

The Permian-Triassic transition on the N Indian margin of the Tethys was the subject of a C isotope analysis by Viorel Atudorei using the previously acquired materials from Kashmir and the Salt Ranges (Atudorei et al., 1995a, b; Baud et al., 1995a, b, 1996).

Figure 14: Peri-Tethys research Group in Dobrogea with Dr. S. Crasquin, 2nd from the left and V. Atudorei starting his PhD studies, 5th from the left, 1985.

The SNF financial support allowed us to continue field research and Permian-Triassic sampling in the Sultanate of Oman from 1996 to 1998 with the help of Jean Marcoux from Paris (Baud et al., 1999).

In 1997, Dr. H. Bucher provided Viorel Atudorei a collection of well dated Lower Triassic carbonate rock from Spiti (N India) and Viorel Atudorei was able to build the first complete Lower Triassic Carbone isotope curve, published in a Chapter of his PhD work. Viorel Atudorei brilliantly defends his thesis under my supervision (Atudorei, 1999). At the University of New Mexico in Albuquerque

(USA), where Prof. Z. Sharp accepted a new position and established a large isotope lab, Viorel Atudorei accepted a research position and launched a successful career there.

3.5 – Research undertaken with Sylvain Richoz (1999-2004)

The new FNSRS Project I submitted "La stratigraphie isotopique et l'étude de la matière organique des sédiments marins du Permien supérieur au Trias moyen", was approved, and Sylvain Richoz, a graduate geologist from Lausanne, was chosen to occupy the position of PhD assistant at the Geological Museum. In September 1999, Jean Marcoux, Sylvain Richoz and I traveled to start fieldwork in the Antalya region of SW Turkey. The three of us maintained these fieldwork efforts in SW Turkey from 2000 to 2003, expanding our study to the Alanya and Taurus region (Baud et al., 2001). We introduced Sylvain Richoz to Permian-Triassic fieldwork in Oman with Jean Marcoux in January 2000 (Baud et al., 2001 ; Richoz et al., 2001a, b).

In May 2002, as a result of Iran's opening to foreign researchers, our research team with Richoz had the chance to spend a month with the Geological Survey of Iran conducting field research and collecting samples from important Permian-Triassic sections in Central and NW Iran that have been published later (Richoz et al., 2010).

This allowed Sylvain Richoz to improve the chemiostratigraphy and the understanding of evolution of three Neo-Tethyan margins (Iran, Turkey and Oman) for the end of the Permian and the beginning of the Triassic and to write his doctoral study that he brilliantly completed and defended in 2004 and published in Richoz, 2006, highlighting the great instability of the inorganic carbon reservoir during the Lower Triassic.

3.6 – From chairman to past-chairman of the International Sub-commission on Triassic Stratigraphy (STS) 1993-2003

In June 1993, I participated in the fieldwork of the Anisian-Ladinian Boundary Working Group in the Italian Dolomites and in Hungary as chairman of the International Subcommission on Triassic Stratigraphy (STS). In November, I was invited to Heidelberg for the European Triassic Basins Study Group meeting.

In 1994, I led the plenary meeting of the STS organized during the "Shallow Tethys 4" Conference, Sept. 9-12, 1994, in Albrechtsberg near Vienna, Austria (Baud. 1994b). During this Conference, a Permian-Triassic Boundary Working-group (PTBWG) meeting and a regional IGCP project 359 meeting were also organized.

In 1995, Maurizio Gaetani was elected as new chairman. In 1996, the STS led a plenary meeting during the 30th International Geological Congress (IGC) in Beijing and the International Commission on Stratigraphy (ICS) approved Maurizio Gaetani as new SST chairman. As the person in charge of motivating the Boundary working group, M. Gaetani received a favorable vote in 1999 from the STS voting members regarding the selection of Meishan as the global Stratotype of the Permian-Triassic boundary (GSSP). In 2000, during the 31st IGC in Rio de Janeiro, the International Commission on Stratigraphy (ICS) ratified this GSSP and approved Mike Orchard from Vancouver (Canada) as STS new chairman.

In 2001, an Opening Ceremony of the GSSP Monument (Fig. 15) was organized in Meishan City during the International Symposium on "The Global Stratotype of the Permian-Triassic Boundary and the Paleozoic-Mesozoic Events" led by Hongfu Yin. I gave a talk at the Symposium and the paper on Griesbachian substage redefinition was published in the proceedings (Baud & Beauchamp, 2003).

Figure 15 : The Ruban ceremony with C. Henderson in the middle and the author (right).

3.7 – Participation in International Geological Congress (IGC), Beijing (China) August 4-14, 1996, and Rio de Janeiro (Brazil) August 7 - September 3, 2000

Appointed by the IGCP Swiss Committee as head of the Swiss delegation to the International Union of Geological Sciences (IUGS), I took part in the work of the 30th International Geological Congress, a congress which was held in Beijing from August 4 to 14, 1996. I was in charge of one of the sessions of the Symposium on "the Permian-Triassic boundary and global Triassic correlation" and presented 2 communications (Baud, 1996 ; Baud et al., 1996). I followed the working sessions of the IUGS and participated in the plenary sessions of the Congress. As past chairman of the Triassic stratigraphy sub-commission, I actively participated in the general assembly of the sub-commission held within the framework of the Congress and went to a Permian- Triassic fieldtrip crossing West China (Fig. 16).

Figure 16: Fieldtrip of the 30th IGC in Beijing, 1996, play with Chinese colleagues.

In 2000, I participated as a guest at the 31st International Geological Congress in Rio de Janeiro (Brazil) from August 7 - September 3. As guest speaker at the Permian-Triassic Symposium, I gave a talk on geochemical variations at the Permian-Triassic boundary (Baud, 2000). I followed Sessions and during the general assembly of the International Union of Geological Sciences (IUGS) held during the Congress, I was appointed chairman of IUGS Commission on Global Sedimentary Geology (C-GSG). After the Congress, I took part in an official excursion, a Geotraverse of the Andes between Mendoza (Argentina) and Vina del Mare (Chile). After the IGC tenure, my report on the accomplishment of the IUGS program GSG from 1987 to 2002 (Baud, 2002).

3.8 – From 1996, a second line of research started: our post-extinction microbial buildups

I discovered a new area of study within my thin section study of the Permo-Triassic collections I stored in the Geological Museum thanks to the IGCP Project 380, "Biosedimentology of Microbial Buildups", with its conference and workshop. Within my examination of the post extinction sediment from the following localities: Curuck Dagh (Turkey), Vedi (Fig. 17b) and Sovetchen (Armenia) and Abadeh (Iran), I received invaluable assistance from Simonetta Cirilli, Professor of Paleontology at the University of Perrugia (Fig. 17a). We presented a poster and abstract on "Biosedimentology of Microbial Buildups" in 1996 with her at the IGCP Project 380 meeting in Göttingen, Germany (Baud & Cirilli, 1996), and a publication we co-wrote with Jean Marcoux c both of which confirmed the idea that the Great Extinction resulted in the immediate resurgence of algo-bacterial buildups (Baud, Cirilli et al., 1997). This new concept was a landmark publication, followed by hundreds of others that fully confirmed it in all regions where the marine limestone layers of the Permian-Triassic transition outcrops.

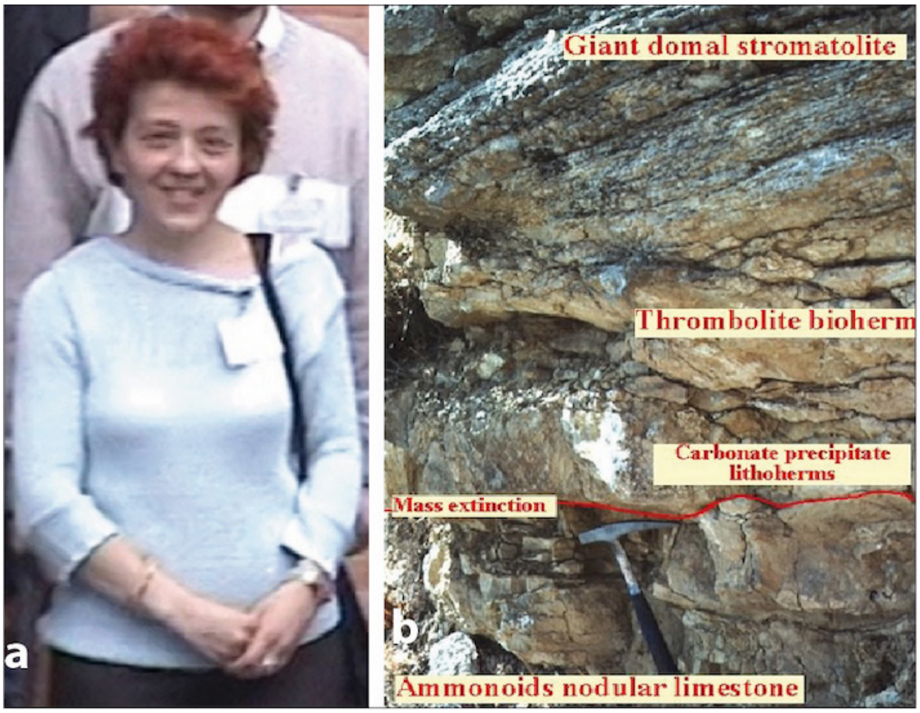

Figure 17 : a) Simonetta Cirilli, b) The post-extinction Vedi Microbial Buildup in S. Armenia.

To understand the Neoproterozoic microbial early-life, and Paleozoic Mud-Mounds, I got the opportunity to participate in 3 field workshops :

1. From Nov. 30-Dec. 6, 1998, I participated in a fieldtrip to Atar (Mauritania). Janine Bertrand-Sarfati and Alexis Moussine-Pouchkine led a 6-day field workshop on the Mauritanian Adrar microbial buildups of the meso-neoproterozoic stromatolites and their environment. I had discussion with the world specialists of Neoproterozoic carbonate and took pictures of giant stromatolite columns (Fig. 18).

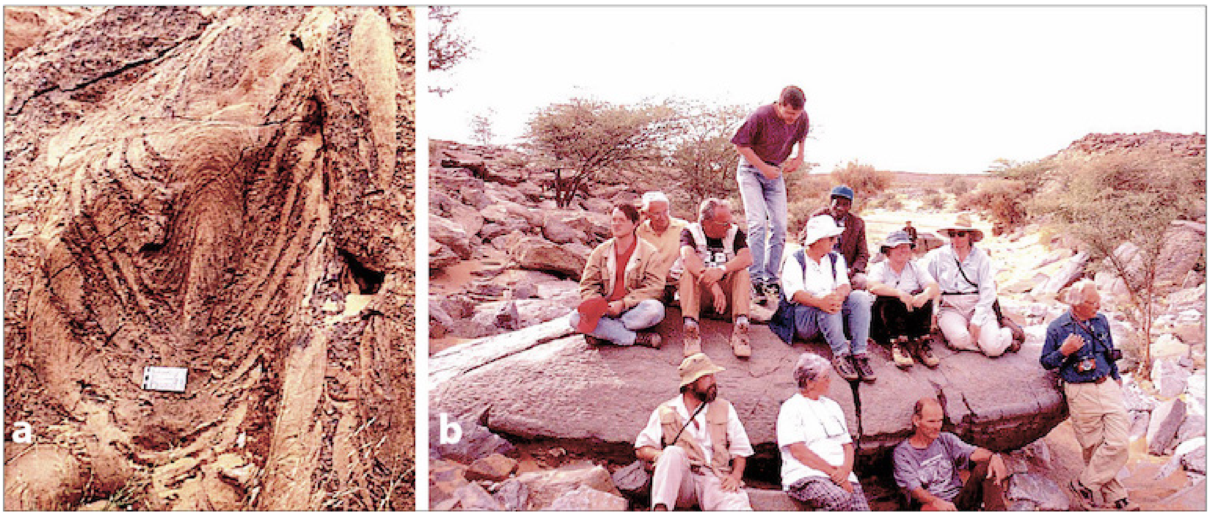

Figure 18 : Atar fieldtrip 1998, a) giant stromatolite columns, b) fieldtrip participants on a stromatolite bowl with J. Bertrand-Sarfati in the middle, down.

2. In 1999, The IGCP Project 380 organized a Fieldtrip to Ouarzazate (Morocco), Sept. 23-Oct. 2. The examinations of Devonian carbonate mound in the area of Ouarzazate were of great interest and the field guidebook became a reference.

3. The third field workshop in Namibia, 2002, was proposed as excursion before the 16th International Sedimentological Congress in Johannesburg (South Africa). Dedicated to the Cambrian Explosion Prelude : the Record of Life and Environments in the Terminal Proterozoic Nama Group, Namibia, in this fieldtrip, I was able to discover under the leadership of John Grotzinger, the best-exposed and most fossiliferous terminal Proterozoic sedimentary rocks along the west coast of Namibia.

With this microbial scientific background, the next field research periods were rich in new post-extinction microbial build-ups discoveries with renewed research teams.

3.9 – A third line of research started : metazoan's escape to the great extinction, a field discovery in Oman

Following the discovery of loose ammonoids, I collected close to a large boulder belonging to basal Triassic olistostrome of large Permian reefoidal blocks, during the Wadi Wasit geological survey with Jean Marcoux in 1997, Leopold Krystyn determined a Griesbachian age for these fossils and went in Late 1988, to sample the Wasit block (Fig. 19) on my precise geographical coordinates.

Figure 19 : L. Krystyn in front of the basal Triassic fossiliferous Wasit block, Oman.

In February 1999, I went back to start fieldworks and Jean Marcoux joined me to work and sample this boulder. With paleontological work done by Krystyn and the thin section's study at the Geological Museum on collected sample, we were able to recognize for the first time a basal Triassic limestone built by fossil accumulations in well oxygenated seawater.

At the 1999 Calgary meeting, I presented lectures on the Oman Permian-Triassic transition with references to it (Baud, 1999), and Krystyn presented a talk and a poster "A unique P/T boundary in the Tethys" with his detailed paleontological work at the Oman Pangea meeting (Krystyn et al., 2001) and the common results of our new research team (Krystyn et al., 2003), attracted a great deal of attention and high citation index. Dr. Richard Twitchett from Plymouth University joined us (Twitchett et al, 2004).

3.10 – Permanent field education for student who applied to study the geology of Oman, 2002

We introduced the geological diversity of the Oman landscape to 13 master's students who were active participants with their structural geology professor, Henri Masson, in January 2002 as part of materials we prepared with Jean Marcoux and Sylvain Richoz for the Lausanne students in Geology association dubbed Pangea (. Dr Heinz Kozur (Hungary) joined the trip and published his own observations (Kozur, 2002).

3.11 – Museum exhibition before retirement in 2003 : an historical view on the last century's High Asia discovery

To end my active life before retirement on a high note, and on a subject that is close to my heart, I prepared with a small close-knit team (P. Forêt & S. Gorshenina), an historical exhibition on last century's High Asia discovery in our temporary exhibition building. It started with Victor Jacquemond (1801-1832) who was the first to discover fossils in Spiti-Himalaya. We gave also information on the geological explorers of the high Himalaya (F. Stoliczka and C. L. Griesbach) who first discovered the basal Triassic Otoceras fauna, and we ended with Arnold Heim and Augusto Gansser and his secret South Tibet geological exploration in 1936.

A highly illustrated book was edited in French at the Olizane edition. "La Haute Asie telle qu'ils l'ont vue. Explorateurs et scientifiques de 1820 à 1940", 152 pages and 120 illustrations (Baud et al., 2003).

To conclude this third period, I would first like to thank the Museum staff, preparators and secretaries who have helped and supported me, as also the laboratory staff, the librarians and thin section preparator of the Earth Science Department of Lausanne Science Faculty for their contributions.

The Lausanne Geological Museum, with its new Permian-Triassic collections and associated publications, has acquired an international reputation, which I was able to pass on to the Museum staff and to my successor on my retirement as director.

4 – The fourth period : end 2003-2010

My retirement as the head of the Geological Museum in Lausanne, and his time-consuming administration, opened a large new field research period, with my Permian-Triassic stratigraphy knowledge, my Carbon isotope chemiostratigraphy and my scientific background on microbial build ups. Without professional obligations, I had the time to write many previously unpublished observations and results from field work, to begin new studies on thin sections of rich Permian-Triassic collections, and to provide encouraging feedback to research teams conducting fieldwork in any open countries.

The Carbon isotope study continued with Sylvain Richoz, a new research line on microbialite with S. Cirilli, J. Marcoux and S. Richoz (Baud et al., 2003), and for the basal Triassic quick recovery research line. R. Twitchett followed our team with J. Marcoux and L. Krystyn. During this fourth period, I was also able to share with colleagues and research teams all of my expertise in organizing field workshops and related symposiums.

Cooperation with paleontologist-stratigraphers continued with Jean Guex and Hugo Bucher on Triassic ammonoids, with Leopold Krystyn, Alda Nicora and from 2007 with Charles Henderson on conodont research. Since 2008, Sylvie Crasquin and Marie-Beatrice Forel have worked together on an ostracode study, and Lucia Angiolini has determined the brachiopods.

4.1 – Participation in International Geological Congress (IGC), Florence, August 18-29, 2004, and Paleontological Congress (IPC), Beijing, June 16-21, 2006

I attended the Field Symposium on Triassic Geochronology and Cyclostratigraphy in St. Christina (Dolomites, Italy) for the first time in September 2003, shortly after I retired from the Museum. During this conference, the Goldhammer's cyclostratigraphy theory received strong criticisms.

For the 2004 IGC, I traveled to Florence, Italy, with Sylvain Richoz's new post-PhD assistant to deliver his PhD research results on the C isotope chemiostratigraphy of Permian-Triassic transition sections from Iran, Turkey, and Oman (Richoz & Baud, 2004). I presented a talk in the late Permian-Early Triassic events session titled "A review of geochemical data on marine sediments of the Permian-Triassic boundary interval" (Baud & Richoz, 2004). During the congress, Bruce Wardlaw presented his Permian-Triassic database program called Chronos, a chronostratigraphic information system and he invited me to participate in the next Spring 2005, Permian-Triassic time-slice project Paleostrat meeting in Boise, USA (Fig. 20).

Figure 20 : Logo of the Permian-Triassic time-slice project.

I attended the Paleostrat workshop for the Permian-Triassic time-slice project in Boise, USA, May 1-2, 2005, as per my invitation. I gave two talks, one of which was about the huge Permian-Triassic specimens hosted at the Lausanne Geological Museum (Baud, 2004) and published on geochemical changes (Baud, 2005).

With Patrice Moix from Lausanne and Sylvie Crasquin from Paris, we went to the Second International Paleontological Congress in Beijing, June 16-21, 2006. I gave a talk (Baud et al., 2006) and was included in two other presentations with Botjer's team and Yin's team (Marenco et al., 2006 ; Yin et al., 2006, 2007a, b). From June 22-28, I took part in the field trip "Upper Paleozoic to Triassic successions of the Tibetan Himalayas and significant geological occurrences along the road leading to the Himalayas". During this fieldtrip, I organized the first sampling with Sylvie Crasquin and Patrice Moix of the lower Triassic Tulong section with his red ammonoid limestone (Fig. 21). This offered us the opportunity to be included in the 2009 and 2011 published papers on the Tibetan Tulong section (Brühwiler et al., 2009 ; Forel et al., 2011).

Figure 21 : Sylvie Crasquin at the lower Triassic Tulong red ammonoid limestone section, Tibet Himalaya.

4.2 – Continuing collaboration in Oman with Jean Marcoux, 2003-2007

As in the past, Françoise and Jean-Paul Breton, who reside in Ruwi/Muscat, provided invaluable assistance, friendship and gave to our research group a home on our arrival in Oman. Dr. Hilal bin Mohammed Al-Azri, Director General of Minerals up to 2005, continued to listen positively to our research programs in Oman.

In preparation for the 2005 field trip, we began fieldwork with Jean Marcoux and Hugo Bucher in the Nizwa region of Oman in January 2004. We later joined our colleagues L. Krystyn from Wien and R. Twitchett from Plymouth who were traveling from the Emirate side to work and collect samples in the Wadi Maqam region (Fig 22).

Figure 22 : Start of field work 2004 in Wadi Maqam (Oman) with L. Krystyn, left, J. Marcoux and R. Twitchett.

Our study team presented three papers at the 24th International Association of Sedimentologists (IAS) meeting, which took place from January 10–13, 2005, at Sultan Qaboos University at Al Khod in the capital city area of Muscat, Oman.

To develop the field guidebook on "Mesozoic evolution of the Tethyan margin of Oman", my colleagues H. Droste, C. Robin, F. Guillocheau, P. Razin, and F. Bechennec collaborated with me (Baud et al., 2005). We held this field workshop from January 4 to 9. Together with S. Richoz, L. Krytyn, J. Marcoux, and R. Twitchett, we wrote the field trip "Birth and Early development of the Tethyan Oman Margin from Middle Permian to Middle Triassic : a geochemical and sedimentological approach" and successfully led the excursion from January 14 to 17 (Richoz et al., 2005).

4.3 – Continued collaboration in Turkey with Jean Marcoux, until his death in 2008, and visit to Spiti/Himalaya (2004) and to New Zealand (2006)

Up until 2007, Marcoux's connection at Isparta University in Turkey greatly aided us in obtaining a field study and sampling permit. Just a week after retirement, in Sept. 2003, I was invited to field research on Permian-Triassic succession of Hazro, in SE Turkey, by Marcoux's research team. We sampled a complete Permian section, and the foraminiferal content were published later (Gaillot & Vachard, 2007 ; Gaillot et al., 2016). With Sylvie Crasquin, we studied the Permian-Triassic transition (Baud et al., 2016

In June 25 to July 10, 2004, with friends, J. Marcoux and our wifes, we reached the Field workshop of the IGCP Project 467 on Triassic Time–in the Himalayan Spiti Province of N India and had opportunity to study and sample the key section on the Permian-Triassic boundary with the *Otoceras* beds.

In May 2005, we went back to SW Turkey for field work with J. Marcoux on Permian paleotectonic of the Curuck Dagh area. We discovered large intra-Permian-Triassic displacements and unconformities, as well as ikaite pseudomorphs' on middle Permian limestone for the first time (Baud et al., 2005),

Along with J. Marcoux and our wifes, we made the decision to travel to New Zealand in March 2006 for a field workshop of the IGCP 467 on the Permian-Triassic radiolarite deposits on the North Island as well as to the InterRad 11 & Triassic Stratigraphy Symposium meeting in Wellington, where we gave two talks (Baud et al., 2006 ; Marcoux et al., 2006). The fieldtrip offered the unique opportunity to observe the world's only section of continuous Late Permian to middle Triassic radiolarite on Arrow Rock Island (Fig. 23).

When I looked at the outcrops beneath the Late Permian radiolarites, I found a pillow-lava basement that was coated in red ammonoid limestone, which served as the foundation for my upcoming research path (Chap. 5.11).

In Sept. 2007, Patrice Moix, a PhD student from Lausanne, asked Marcoux and I to have a look at his PhD fieldwork in an area near Mersin, S Turkey. Thereafter, we went to Alanya area and discovered a new PTB section at Oznurtepe. It was my last fieldwork with him.

In May 2008, due to Marcoux's illness, we carried on the fieldwork with Sylvie Crasquin, her PhD student M.B. Forel, and a newcomer named Steve Kershaw who was interested in microbialite and published it (Kershaw et al., 2011, 2012). I coached L. Angiolini's PhD student, V. Verna, on Permian brachiopod sampling in Curuck Dagh area, SW Turkey, alongside Prof. Alda Nicora (Verna et al., 2011). All our team also prepared an IGCP 572 field workshop in Antalya for 2009.

Figure 23 : InterRad participants looking at the world's only lower Triassic radiolarian chert on Arrow Rock Island, New Zealand, 2006, with H. Kozur sitting in the back.

We had just returned from conducting fieldwork in Jean's favorite area of study—the Antalya Mountains of South Turkey—when we learned of his sudden death on June 17, 2008. We were all deeply saddened to learn of that. Some of us participated in his burial ceremony in the famous Père Lachaise cemetery in Paris. Having spent over 25 years of geological adventures with him, writing together, organizing meetings or geological expeditions, I immediately started to write tribute papers in our Permian and Triassic newsletters and in introductions of our field guidebooks on Turkey and Oman (Baud, 2008, 2009 a, b, 2010).

4.4 – IGCP's new project 572 will pay tribute to Jean Marcoux at two conferences we've organized on the fields he covered so much.

Under the leadership of Zhong Qiang Chen (Australie) the aim of the IGCP Project 572 was to investigate the recovery of ecosystems following the end-Permian mass extinction through analyses of the rock and fossil records via studies of biostratigraphy, paleontology, paleoecology, sedimentology, geochemistry and biogeochemistry.

The Second IGCP 572 Annual field workshop took place in Antalya, Southern Turkey, from September 2nd to September 6th, 2009. As a co-organizer, I oversaw the opening session dedicated to Jean Marcoux's memory and reminiscing about his extensive scientific career and contributions to our understanding of the Permian and Triassic periods. The assistant professor E. Kosun has helped organized a one-day meeting for September 3 at the Engineering Faculty Akdeniz University in Antalya. In my speech, I went over each stop on the 3-day field workshop that S. Crasquin and S. Kershaw and I had planned for September 4-6 (Crasquin et al., 2009).

The Third IGCP 572 : Annual field workshop took place in Oman from February 20–26, 2010. The meeting, led by Professor Michaela Bernecker, lasted one and a half days at GUtech in Muscat and a talk pay tribute to Jean Marcoux Oman's fieldworks.

The four and a half-day field workshop excursion, led by O. Weidlich, A. Baud, B. Beauchamp, L. Krystyn, A. Nicora, C. Henderson, S. Richoz, F. Cordey, and R. Twitchett, gave participants the chance to see the stunning outcrops of the Oman Mountains (Fig. 24), which offer unmatched access to the Permian-Triassic transition units along the Gondwana margin of the Tethys (Baud, & Bernecker, editors, 2010).

Figure 24 : Group photo of the IGCP 572 annual field workshop participants on the Saiq Plateau, 2000 m. high, Oman.

4.5 – Continued collaboration with Benoit Beauchamp, Charles Henderson and Steve Grasby, 2003-2010

In 2003, the Pangea Special Issue edited by B. Beauchamp was issued. I participated in the I.C.E. 2004 CSPG joint conference in Calgary, Canada, and the Beauchamp research team used two of my contributions in papers that were presented there (Beauchamp et al., 2004a, b).

B. Beauchamp asked me to speak to his students at Calgary University in 2005, and I accepted the invitation. On my recommendation, the research on the Permo-Triassic in Oman was continuously carried out in partnership with Benoit Beauchamp, Charles Henderson, and Steve Grasby, and they received financial support for it. As a result, the Beauchamp research team along with Noel James from Kingston (Canada) and Alda Nicora from Milano traveled to various important Permian-Triassic outcrops (Fig. 25), from Central Oman to Wadi Maqam near the Emirates border in January 2006 for fieldwork.

Figure 25 : The Beauchamp research team with A. Nicora in the middle, collecting Permian red ammonoid limestone in Rustak (N Oman).

I participated in the Boreal Triassic Conference at Longyearbyen, Svalbard, Arctic Norway in August 2006, and give a talk on the lower Triassic bryozoan beds I discovered on Ellesmere Island during the 1994 field work with B. Beauchamp. The research report by the Beauchamp research group in collaboration with the bryozoan expert Prof. Hans Nakrem from Oslo was published in Polar Research (Baud et al., 2007).

We traveled with B. Beauchamp to many significant Permian-Triassic outcrops in Oman in January 2009 to prepare for the second IGCP 572 field workshop, Sultanate of Oman, scheduled for 2010. In September 2009, following the IGCP 572 field workshop, in Antalya, I led Charles Henderson to discover some Permian-Triassic outcrops not included in the workshop.

The second IGCP 572 field session was actively attended by the Beauchamp research team in the Sultanate of Oman in 2010.

4.6 – New collaboration with Prof. Dave Botjer from UCLA, his doctoral students Sara Pruss, Pedro Marenco, Dr. Frank Corsetti and Dr. Adam Wood, (Los Angeles, Ca, USA), 2003-2008

I asked in 2003, Sara Pruss and Dave Botjer to explore with me the Permian-Triassic units of the Antalya Mountains in southern Turkey. They collected samples and enthusiastically encouraged me to join them in a 2004 study of the US West Coast Triassic.

F. Marenco examined S isotope of the samples, after which he sent a common abstract for the 2004 GSA annual meeting. In May 2004, I joined the UCLA Permian-Triassic team for a field workshop on Nevada-California lower Triassic outcrops and went to Darwin Hills lower Triassic limestone (Marenco et al., 2004).

In March 2005, I joined Sara Pruss for field work on the Triassic of the Darwin Hills and in Muddy Mountains close to Las Vegas.

I attended the International Symposium on Triassic Chronostratigraphy and Biotic Recovery in Chaohu, China (Fig. 26), from May 23–25, 2005, together with Sylvain Richoz new post-PhD assistant. We met the D. Botjer research group at the symposium, where I presented a talk on the lower Triassic anachronistic carbonate facies in space and time, along with S. Richoz and S. Pruss. The talk was published in (Baud et al., 2007). Marenco and Corsetti team presented the S isotope anomalies across the PTB (Marenco et al., 2005).

Figure 26 : Group photo of the participants to the Chaohu meeting, 2005, D. Botjer and I are second in the right front.

The same year, D. Botjer was in charge of a C.R. Palevol special volume on "The Triassic recovery, the dawn of the modern biota" and we had the opportunity to publish one paper with Marcoux and Richoz on Turkey basal Triassic calcimicrobial cap rock (Baud et al., 2005), and one with the Corsetti and Marenco team in association with Richoz on "Summary of C isotope records" (Corsettti et al., 2005).

In 2006, S. Pruss, D. Botjer, and I collaborated on a paper for Earth Science Review that compared the post-extinction responses of S Turkey and W USA from fieldwork conducted in Turkey and the USA in 2003 and 2005 (Pruss et al., 2006).

In 2008, S. Pruss and I traveled to Bolzano for the Workshop on Triassic Paleoclimatology, where we spoke and looked for opportunities to conduct fieldwork in the S Alps Middle Triassic near Bagolino (Pruss, & Baud, 2008).

In January 2005, as Dr. Adam Wood attended the IAS meeting in Muscat, Oman, I urged him to begin field investigation and sampling on the lower Triassic red ammonoid limestone of the Baid outcrop (Fig. 27). He invited me to present "Unusual Lower Triassic Seafloor Precipitates from Oman" at the GSA annual meeting 2006 in Philadelphia, USA (Woods & Baud, 2006), following my successful research on this limestone. In 2008, our article on "Anachronistic facies from a drowned Lower Triassic carbonate platform of the Oman Mountains" was published (Woods & Baud, 2008). With Sylvain Richoz we developed this research in 2013 (Chap. 5.5) .

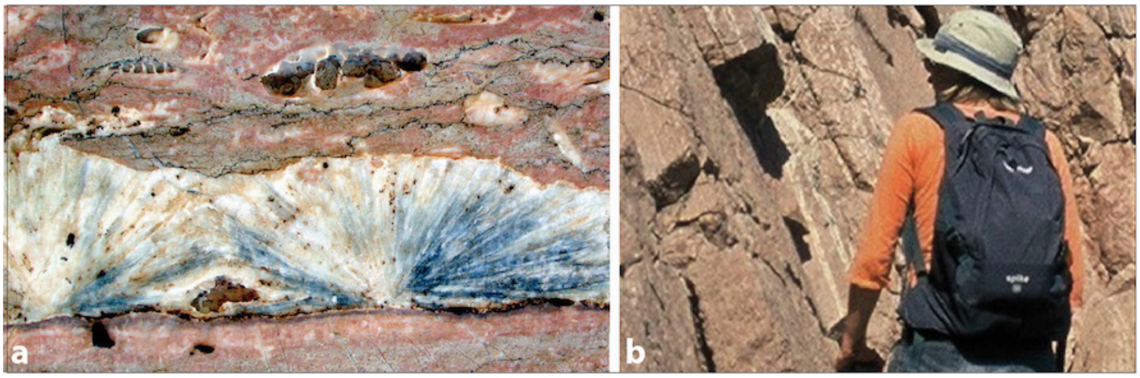

Figure 27 : The Olenekian red ammonoid limestone of Baid, Oman, a) Unusual Lower Triassic seafloor precipitates overlain by ammonoid, b) Adam Wood examining the outcrop.

4.7 – Geological consultant, 2005-2008

In response to the need for scientific knowledge in my area of expertise, I created the position of Geological consultant, named BGC, during my retirement at the request of my friend and colleague Jean Paul Breton, who oversees an Exploration Consultants office in Muscat, Oman (Fig. 28). I had the responsibility of providing J.P. Breton, with expertise on the Permian breccias of the Jebel Akhdar for the purpose of exploiting colored marble in May 2005.

In March 2007, I was asked to provide a guidebook and to lead a 3-day field excursion for Total SA geological experts, on the Permian-Triassic carbonate succession of the Saiq Plateau in Oman (Baud, 2007).

At least, I worked with J.P. Breton on the Triassic breccia of the Wasa Mountains South of Wadi Maqam in northwest Oman in January 2008.

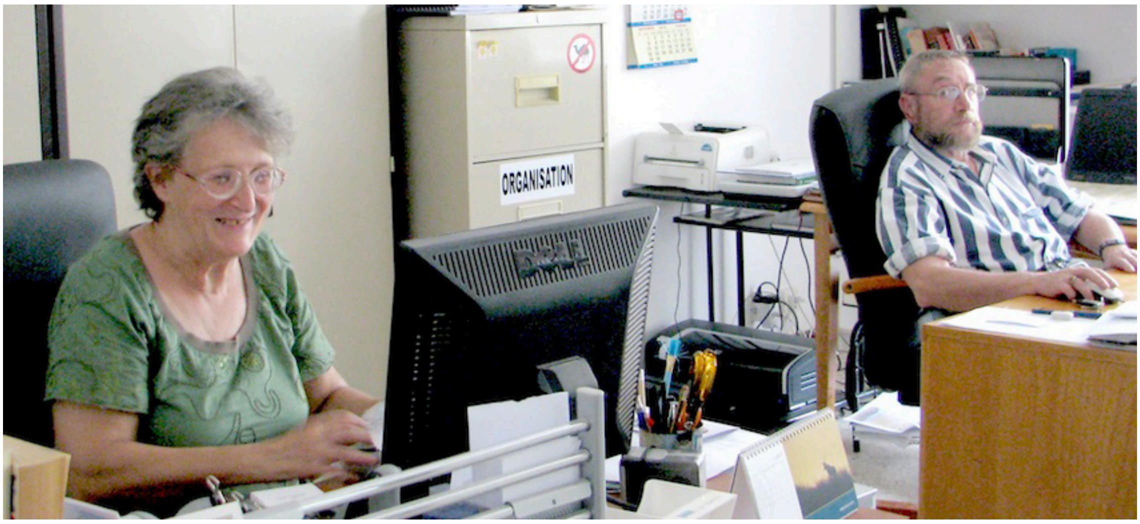

Figure 28: The Exploration Consultants office in Muscat, with Françoise and Jean-Paul Breton.

4.8 – Start of continuing geological education for French high school teachers (CBGA)

In 2009, I was approached by Thierry Juteau, a honorary professor of geology from Brest University and an expert in ophiolite rocks, to co-lead a geological expedition in the Oman Mountains and co-write a field handbook. Thierry Juteau is also the supervisor of the continuing geological education program for French high school teachers (Juteau et al., 2009). I went on the trip towards the end of October 2009 with some friends and I was involved in presenting the best outcrops for understanding the geology of Oman and teaching it to high school students. The continuation of this involvement is presented in chapter 5.12.

5 – The fifth period: 2011-2023

Cooperation with paleontologist-stratigraphers continued with Profs Jean Guex, Hugo Bucher, and Dr. Thomas Brühwiler on Triassic ammonoids, with Profs Nicolas Goudemand, and the PhD students Morgane Brosse and Marc Leu newcomers to lower Triassic conodont of South China, Kashmir and Oman. My research on conodonts with Francis Hirsch and Pablo Placensia gave me a fresh perspective on the middle Triassic strata of the Swiss Prealps.

Applying earlier research avenues to new field study areas enables discoveries and opens up new avenues. Opportunity came to help organize international field workshops due to openminded local colleagues who welcomed the UNESCO IGCP projects.

The permanent geological education programs continued with the French high school teachers and were expanded to include Lausanne PhD students.

5.1 – Fieldwork in Oman, the Austrian research team with Sylvain Richoz, Leopold Kystyn and Rainer Brandner, and the Canadian research team with Benoit Beauchamp, Steve Grasby and Charles Henderson

In January 2011, just one year after the IGCP 572 workshop, we started field work with L. Krystyn in the Batain (Oman) and J. Guex joined us and when I discovered the fossiliferous Asselah block, looking at the silicified ammonoid on the surface, both specialists agreed on the Griesbachian, basal Triassic age of this block. As they showed no interest in studying it, I began talking about what we did in the ensuing years with H. Bucher in Zurich, who was prepared to embark on a new research project with PhD students.

Along with S. Richoz, I attended the EAG Permian-Triassic conference in Kuwait City in December 2011. We presented two talks and a report on the 2010 IGCP field workshop in Oman (Baud et al., 2011; Richoz et al., 2011).

In 2012, I went with S. Richoz to the International Conference on the Geology of the Arabian Plate and the Oman Mountains from 7-9th January 2012, at Sultan Qaboos University, Muscat, (Fig. 29) and we gave 2 talks and published our results in collaboration with the Canadian team (Baud et al., 2012a, b; Richoz et al., 2012a, b).

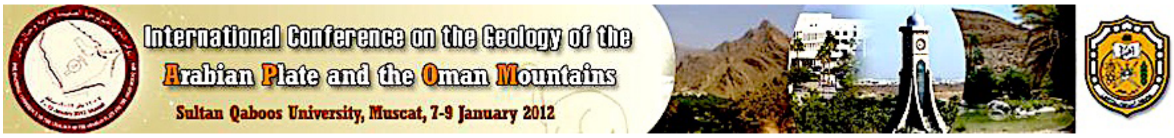

Figure 29: Group photo of part of the participants of the Conference in front of the Sultan's Palace.

The 2013 research by S. Richoz is showcased in the emerging field of study on the link between microbial buildups and post-extinction metazoan sponges, see chapter 5.7.

In 2015, B. Beauchamp came back to Oman, for field work and I went with him on the Saiq Plateau and in the Batain plain to deepen our study on the Permian limestone succession.

At the 31st IAS Meeting of Sedimentology, which took place in Krakow, Poland, from June 22–25, 2015, some of our findings were presented (Beauchamp et al., 2015), and in 2018 in Quebec City, Canada, during the International Sedimentological Congress (Beauchamp & Baud, 2018).

5.2 – From 2011, field work in Oman with Prof. Hugo Bucher and his PhD students from Zurich University and Museum

The new partnership with Hugo Bucher and his PhD students began in 2018 and continues to this day inside the study group on Permian-Triassic transitions at Paleo C4 - Sinergia Swiss University research group.

Each year's field work in Oman, got the discrete help of Professor Michaela Bernecker living and working on-site in Muscat, for stewardship and preparation of fieldworks tools. It was with her and Oliver Weidlich, that we organized the excursions to the "12th International Symposium on Fossil Cnidaria and Porifera" held in GuTech in 2015 (Baud & Weidlich 2015).

We started field work in November 2011, to study the Asselah block in the Batain, with Asa Frisk PhD student and Dr Nicolas Goudemand, and to sample this new basal Triassic fossiliferous block, just 10 months after my discovery with L. Krystyn and J. Guex (Baud et al., 2015 ; Brosse et al., 2019).

We traveled in December 2012 with Hugo Bucher as part of the project "The Permian mass extinction and Early Triassic recovery of Eastern Oman" to explore the Batain and Wadi Wasit areas. In December 2013 and January 2015, we returned to Batain research with a PhD student named Romain Jattiot. In January 2017, Marc Leu, a PhD student joined us to study the red ammonoid limestone of Wadi Musjah (Baud, 2013a) and new lower Triassic blocks in the Batain. Same year in December, we went to Djebel Rabat area and in January 2018, we achieved the sampling of the lower Triassic fossiliferous boulders and buildups of the Batain with H. Bucher and T. Brühwiler.

From 2018, Oman samples stored in the Geological Museum of the Zurich University have been under study by teams of Professors and PhD students from Lausanne and Zurich for paleontological determination and geochemical study with funding from the Synergia FNSRS program. The main results have been presented at Geological Conferences and published in papers and in PhD thesis chapters of Morgane Brosse (Brosse et al., 2017), Marc Leu (Leu et al., 2021, 2023), Zoneibe Luz (Luz et al., 2023), Franziska Blattmann (Blattmann et al., 2023) and Oluwasser Edward (Edward et al., 2023).

5.3 – The Geological Society of Oman (GSO) : Collaboration continues, 2011-2015

During my stay in Muscat, my proposals to give a talk or to lead a fieldtrip on the Permian or Triassic was always welcome. This is the reason I offered to take the Society members to the Buda'yah section in January 2011 (Fig 30).

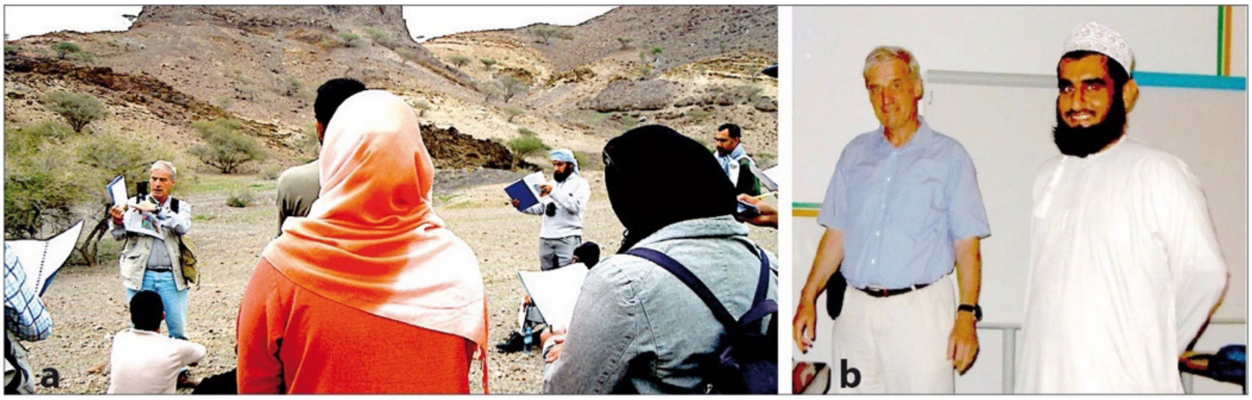

Figure 30 : a) Geological explanations in the field, b) The author with Dr. Mohammed Alkindi, Chairman of the GSO.

This is the only location where middle Permian radiolarite is directly lying on pillow lava substratum. It was suggested that this location be included in Oman's geological heritage because it provides a unique record of the oceanic environments of the Neotethys from the Middle Permian to the Early Triassic (Baud, 2011).

The Khuff Margin in the Oman Mountains has been the focus of my conference in November 2013. In February 2015, I gave a talk on Oman oases : contrasting carbonates sediments on the Gondwana margin in the immediate aftermath of the Permian-Triassic (from Baud et al., 2014).

5.4 – Field work in the Guangxi S China and in Kashmir NW India with Prof. Hugo Bucher and his PhD students from Zurich University and Museum

Among my fieldwork locations, the Guangxi province in southern China was unfamiliar to me. I was touched by the warm welcome I received from Kuang Guodun, a retired geologist from the Guangxi Bureau of Geology, who led Bucher's research team in important Permian-Triassic outcrops in his area of expertise.

We started field work in March 2011 with H. Bucher, PhD student Åsa Frisk and Kuang Guodun, visited and sampled about 15 Permian-Triassic boundary (PTB) and Lower Triassic sections in north Guangxi province. The next field works were in February 2012 with the same team and a newcomer, Morgane Brosse, a PhD student and we extended our research to the whole Guangxi province and sampled almost 15 PTB sections (Brosse et al., 2013, 2015, 2016 ; Bagherpour et al., 2015, 2016, 2017 ; Hautmann et al., 2015).

One of them, the Shangan section opened a new line of research which will be presented in chapter 5.5.

The opening of the Indian Kashmir in 2012, after 25 years blackout, offered me the opportunity to coach PhD students with the precious help of Professor Ghulam Bhat from University of Jammu, India. In May 2012, I led a group of PhD students, including Dr. Nicolas Goudemand, Marc Leu, Max Meier, and Morgane Brosse, to the Guryul Ravine area where we conducted research on the Permian-Triassic boundary and the lower Triassic succession (Brosse et al., 2013, 2017). We were accompanied by G. Bath. Additionally, we conducted several local surveys looking for fresh PTB sections (Fig 31).

Figure 31 : Our 2012 research team in Kashmir with Kashmiri colleagues and Prof. Ghulam Bhat second from left.

Under the guidance of G. Bath, our small team returned in October 2013 to complete the lower Triassic Guryul Ravine study. Some results were presented at the 19th International Sedimentological Congress 2014, (Leu et al., 2014), and our team with H. Bucher published 2 papers (Brosse et al., 2017 ; Leu et al., 2023). The main common results are in the PhD thesis of Dr Morgane Brosse (2017) and of Dr Marc Leu (2021).

5.5 – A new line of research : The post-extinction metazoan sponge link to the stromatactis bearing limestone, 2011-2015

When Bucher's research team and I discovered a post-extinction basal Triassic stromatactis limestone in the Dongpan area of southern China in 2011, I became aware of the significance of sponges since we knew that stromatactis originated from sponge collapse in carbonate-forming rock. For this reason, in addition to giving a talk and writing an abstract for the IGCP 572 closing meeting in Egger, Hungary, (Baud et al., 2012a), I also attended the 29th IAS Meeting of Sedimentology in Schladming, Austria, (Baud et al., 2012b), the GSA Annual Meeting in Charlotte, Charlotte USA (Baud et al., 2012c), and the World Summit on P-Tr mass extinction & extreme climate change in Wuhan, China, in 2013 (Baud et al., 2013).

Working with S. Richoz on the Olenekian Baid red limestone of Oman in 2013, we examined the thin sections once more (see chap. 4.6). We also sent an abstract titled " The Smithian (Early Triassic) red ammonoid limestone of Oman, refuge for sponge–microbial build-ups during a recovery phase " (Baud & Richoz, 2013) and presented our findings at the 12th International Symposium on Fossil Cnidaria and Porifera, which took place at GuTech, Muscat, Oman, (Baud & Richoz, 2015).

5.6 – Fieldwork in Iran and in Turkey with Sylvain Richoz and the Austrian research team : Leopold Krystyn, Rainer Brandner and newcomers, Micha Horacek, Katrin Heindel and Paul Beckman

Thanks to Dr. Taipeh Mohat, Chief Geologist at the Iran Geological Survey, who extended the invitation and oversaw our research team in the field, we were able to accept the invitation to return to Iran in 2011. With the Austrian research team, we received 2 weeks financial support and opportunity to study five Permian-Triassic boundary sections in Zagros and in Central Iran, from May 16th to 30th 2011 (Heindel et al., 2013, 2015, 2016, 2017, 2018a). As detailed in Chapters 5.7 and 5.8, these fieldwork activities with our research team enabled us to expand my observations on the geometry and spatial distribution of the microbial buildups, in the important Shareza and Abadeh areas.

In Turkey, Dr. Erdal Kosum of Antalya University assisted us and actively participated in our Permian-Triassic fieldwork in the Antalya and Alanya region (Fig. 32) in April 2012 (Heindel et al., 2018b).

5.7 – Fieldwork in Armenia with Sylvain Richoz, the Austrian research team and Evelyn Friesenbichler, PhD student participated in the published papers

Thirty years after my first geological visit, I received an invitation to return to Armenia, thanks to Professor Lilit Sahakyan, who guided us in the field, helped organized our field research, and welcomed us in Erevan. The Armenian Academy of Science invited the Austrian research team, consisting of

Sylvain Richoz, Leopold Krystyn, Rainer Brandner, and PhD student Evelyn Friesenbichler, to begin Permian-Triassic study in Armenia in 2014. We spent ten days, from September 27 to October 7, 2014, to study important Permian–Triassic sections.

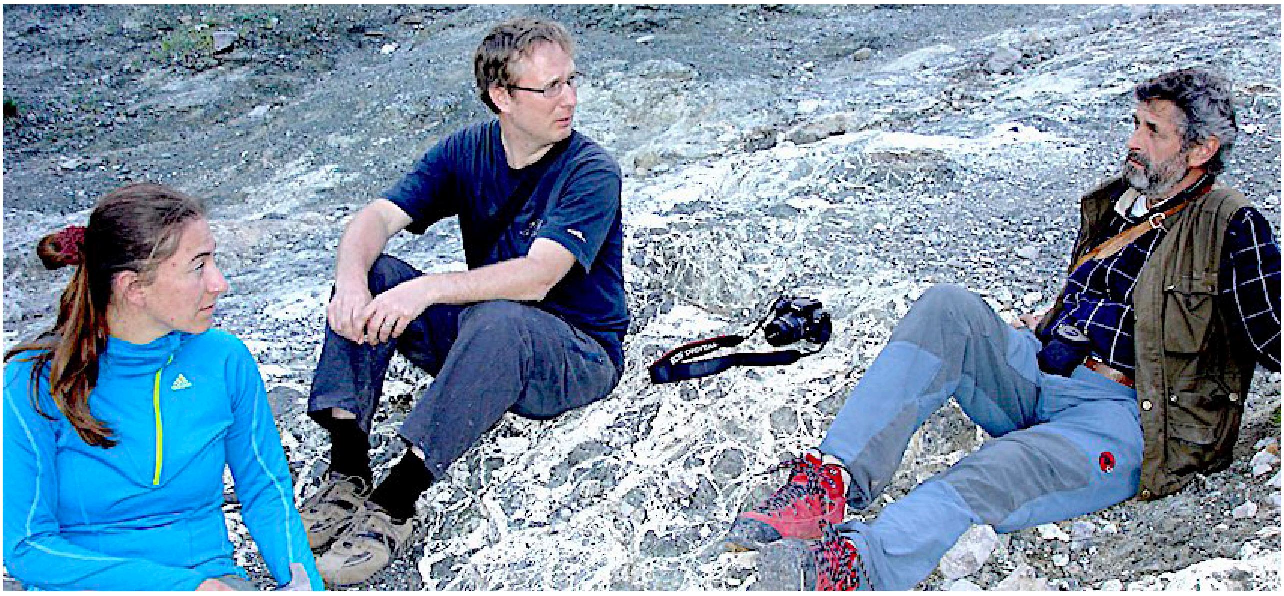

Figure 32 : Field work near Alanya, discussion between K- Heindel, left, S. Richoz and R. Brandner.

Thanks to our collaboration and my prior field experience, we were able to expand our new line of research, which I described in Chapter 5.8, by gaining a deeper understanding of the complexity of post-extinction buildups and the role of sponges.

Together with our Armenia PT Geology research team, we submitted an abstract and presented a talk titled "Giant microbial buildups of earliest Triassic in Armenia" at the Goldschmidt Conference in Prague, Czechia (Baud et al., 2015) ; the 2nd International Congress on Stratigraphy, July 19–23, Graz, Austria (Friesenbichler et al., 2015) ; and the 2016 GSA Annual Meeting, Denver, Colorado, USA (Friesenbichler et al., 2016). During the Armenia IGCP 630 field workshop in Erevan, we presented our results in an abstract and on the detailed field guidebook presented in Chapter 5.10.

5.8 – An extended line of research : The post-extinction metazoan sponge link to the microbial buildups, 2016-2021

With Katrin Heindel, we sent an abstract and presented a talk on "Earliest sponge-microbialite reefs on Neotethys platform margins in the Early Triassic" at the Dolomieu Conference on Carbonate Platforms and Dolomite, Selva di Val Gardena (Italy), and at the 2017 GSA Annual Meeting in Seattle, Washington, USA and at the 5th IPC, Paris July 5-9, 2018 (Heindel et al., 2018b).

As part of Evelyn Friesenbichler's PhD student thesis work (Fig. 33) and in collaboration with William Foster, a recent addition to our Austrian-Armenian research team. "Sponge-microbial build-ups from the lowermost Triassic Chanakhchi section in southern Armenia" was submitted and published (Friesenbichler et al., 2018). A next paper, "The formation of microbial-metazoan bioherms and biostromes following the latest Permian mass extinction", was submitted and published (Foster et al., 2018).

Figure 33 : a) part of the build-ups from the lowermost Triassic Chanakhchi section in southern Armenia, b) Evelyn Friesenbichler on this section of her PhD.

During the International Sedimentological Congress in Quebec City, Canada, August 12–17, 2018, I presented an abstract and a talk that expanded our discovery of the earliest Triassic sponge-microbialite reefs in Armenia to our basal Triassic succession of microbialites in Central Iran (Baud et al., 2018). Another new perspective of the basal Triassic sponge-microbial buildup as a time specific facies on the Central Iran and Armenia Cimmerian margin was proposed with S Richoz and in 2019, we sent an abstract and gave a talk at the 3rd International Congress on Stratigraphy, Milano, 2-5 July 2019 (Baud & Richoz, 2019).

I completed our collaborative article on "Sponge takeover from End-Permian mass extinction to early Induan time : Records in Central Iran microbial buildups" in 2020 with Micha Horacek as a newcomer. It was published in Baud et al. (2021).

5.9 – Stratigraphic readjustment of the Swiss Prealps middle Triassic carbonate succession, a collaboration with Francis Hirsch, Pablo Plasencia and Sylvain Richoz

As the stratigraphy and paleontology of the Triassic conodont have progressed, and in light of the favorable collected rocks found in the *Costatoria goldfussi* limestone, which is situated 650 meters above the sequence base at the Wiriehorn and Rothorn localities in the Swiss Prealps, I made the decision to gather residues following the dissolution of the limestone. Dr Heinz Kozur invited in 2002 by the Geological Institute looked at it and apparently recognized the species *truempyi*, but never confirmed it. The extract conodonts were handled by PhD candidate Sylvain Richoz, and it wasn't until 2009 that I got in touch with Dr. Francis Hirsch, who had moved to Japan. Having recently completed research on conodonts identical to his own, he wrote to Dr. Pablo Plasencia in Spain, expressing his keen interest (Plasencia et al, 2016, 2018). With the help of F. Hirsch, P. Plasencia was able to verify the identification of *Sephardiella truempyi* (HIRSCH) and the brief existence of this confirmed species at the base of the Ladinian stage when he visited Lausanne to examine the recovered material.

That's the reason I began working with them to revise my 1984 stratigraphy of the Swiss Prealps' middle Triassic succession, which we successfully published with fresh insights into the entirety of the Briançonnais' middle Triassic in the Western Alps, as well as the Early Ladinian marine transgression over part of Western Europe (Baud et al., 2016).

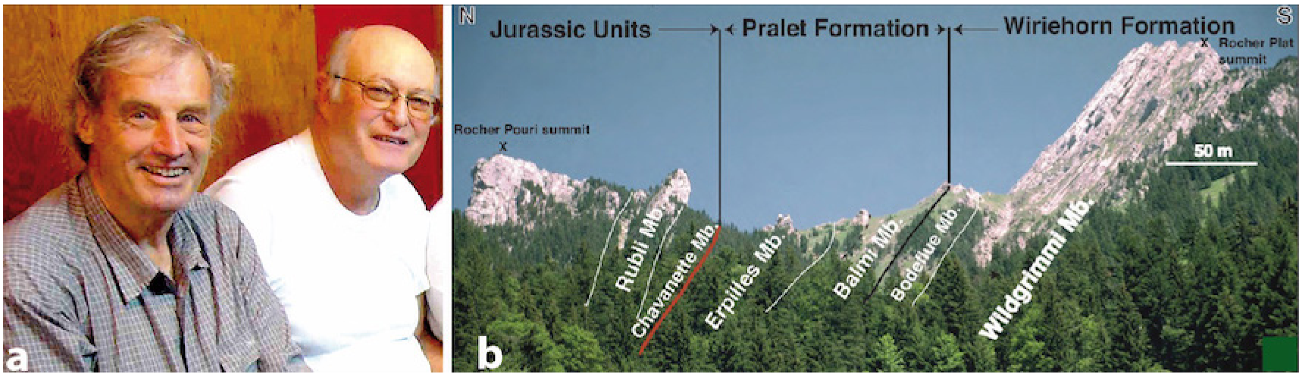

Figure 34 : a) Francis Hirsch, right, and the author, b) View on the type locality (stratotype) of the Pralet Formation, Ladinian, Swiss Prealps.

5.10 – IGCP 630 field workshops : Kashmir, Armenia and China, 2014-2018

My involvement in IGCP project continued with the IGCP Project 630 and his leader, Prof. Zhong Kiang Chen of the Wuhan University of Geosciences (China). I took the opportunity to suggest a field workshop with Professor Ghulam Bhat, and we invited Professor Zhong Kiang Chen Chen, to collaborate with us in organizing the first IGCP 630 workshop in Kashmir, which we agreed to take place in November 2014. I coordinated the field workshop with G. Bhat and wrote the field guidebook based on my previous data (Baud et al., 2014a), and the report (Baud et al., 2014b).

I suggested to Prof. Lilit Sahakyan that she welcome a field workshop in Armenia, much as I did with Prof. Ghulam Bhat. We asked Prof, Zhong Kiang Chen, leader of IGCP 630 project, to organize it with us. This second IGCP 630 workshop was held from October 7-15, 2017, with 2 days talks in Erevan under the leadership of Lilit Sahakyan, followed by 6 days in the field (Fig. 35). I gave a talk and we presented our final results in an abstract (Baud et al., 2017), on the field guidebook (Sahakyan et al., 2017a) and on report (Sahakyan et al., 2017b).

Figure 35 : Group photo of the IGCP 630 field workshop participants on the Zangakatun section of S Armenia, 2017.

The closing meeting of IGCP 630, was held from May 22-24, 2018, in Wuhan, China. Following my presentations on the outcomes and perspectives from the previous ten years of IGCP 630 and 572 field meetings (Baud, 2018), L. Sahakyan included me in her presentation on the 2017 Armenian field conference (Sahakyan & Baud, 2018). I received a IGCP Honorary Award. The journal article I authored regarding these final results was published in Baud et al. (2018).

5.11 – The time specific facies of Middle Permian, of Latest Permian and of Early Triassic red ammonoid limestone, from New Zealand, Timor, Himalaya to Iran, Armenia and Oman open a new line of ongoing research.

Through our field research, we have accumulated data on red ammonoid limestones and have had the opportunity to present some data on those from Middle Permian (Guadalupian) in Baud et al. (1993) and in Marcoux & Baud, (1996). About Timor some data are in Baud & Marcoux, (1991), and about Oman in Pillevuit et al. (1997), Baud et al. (2001b), Kozur et al. (2001a, 2001b) and Richoz et al. (2013).

Late Permian red ammonoid limestone facies have been illustrated in Armenia in Sahakian et al. (2017) and both Armenia and Iran by Baud & Richoz, (2019).

The Lower Triassic facies, which includes the red ammonoid limestones described in Oman, the Himalayas and Timor (Fig. 36), were presented by the author at the First Joint Scientific Meeting of GSC and GSA in Chengdu (Baud, 2013a).

An approach to these facies specific to certain time periods (Middle Permian, Late Permian and Olenekian) was presented in Beijing by Baud & Bucher (2019) and work is in progress for publication.

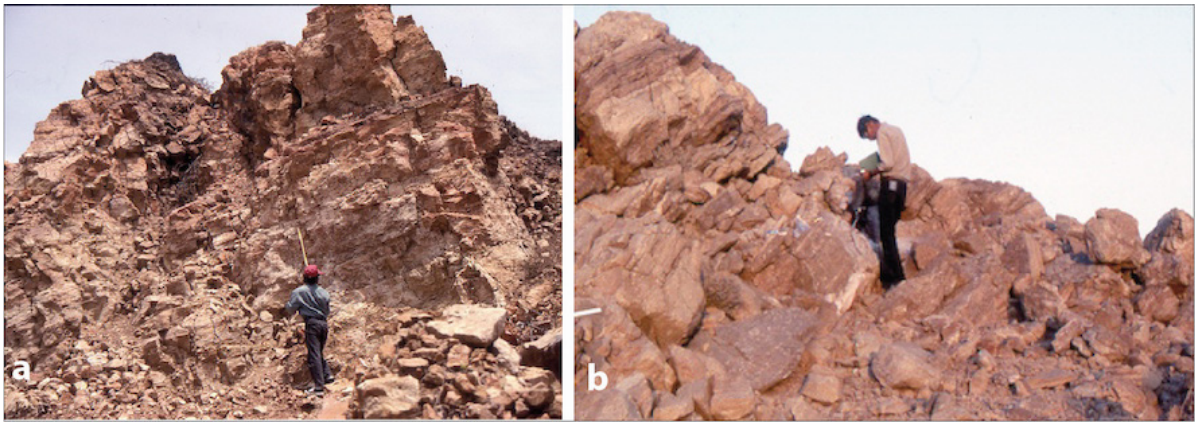

Figure 36 : The Olenekian red ammonoid limestones a) The overturned section of Basleo, Timor, b) The Wadi Musjah section of north-east Oman.

5.12 – Continuing geological education is offered to French high school teachers and the doctoral school to Lausanne students, 2011-2016

At the end of October 2011, I again collaborated with Thierry Juteau to lead a geology and ophiolite excursion of the Antalya Bay (South Turkey) and to co-author the field guidebook for the French high school teachers (Juteau & Baud, 2011).

At the end of October 2014, I led a fieldtrip on the Swiss Prealps Trias and wrote a field guidebook.

At the end of October 2016, I organized and led a 10-day geological education fieldtrip in South and North Oman and wrote the field guidebook (Baud, 2016).

In February 2016, I co-organized a 10-day Lausanne doctoral school in the Oman Mountains and the Batain Plain with Prof. Stefan Schmalholz of the Geological Institute of the University and Prof. Jean-Pierre Burg from ETH Zurich, with the aim of providing the PhD student in Geology from Lausanne with continuing geological education (Figure 37). I also co-authored the field guidebook for the program (Burg & Baud, 2016).

Figure 37 : Participants of the Lausanne doctoral school on Olenekian papery limestone of the Buday'ah outcrop of N. Oman, b) J.P. Burg and the author.

5.13 – Dedication of two genera and three new species bearing my name and described by paleontologist's colleagues.

In paleontology and geobiology, it's customary to name fossil organisms after known researchers to honor them. Two genera (*Baudiella* and *Baudicrinus*) and 3 species names (*baudi*) of fossil organisms including an ostracod, two foraminifera, a crinoid and an ammonoid have been dedicated to me, for my fieldwork and publications :

1. In 1998, foraminiferal specialists Demir and Ozkan-Altiner dedicated the new genus *Baudiella* to the director of the Lausanne Geological Museum, for his contribution to the study of the Permian-Triassic of the Tethys (Altiner & Ozkan-Altiner, 1998).
2. In 2015, Tatsuo Oji, a specialist in Sea Lilies (Echinoderms), together with Richard Twitchett, dedicated the new genus *Baudicrinus* to Aymon Baud, who first discovered a limestone boulder of Griesbachian age in the Wadi Wasit in Oman, and the species *krystsyni* to Leopold Krystyn, who determined and confirmed it (Oji & Twitchett, 2015).
3. In 1996, ostracod specialist Sylvie Crasquin dedicated the species *Polycope baudi* to the director of the Musée de Géologie in Lausanne, in recognition of his successful participation in geological research in the Triassic Dobrogea in Romania (Crasquin-Soleau, 1996).
4. In 2007, Permian foraminifera specialists Jérémie Gaillot and Daniel Vachard dedicated the species *Labioglobivalvulina baudi* to Aymon Baud of the University of Lausanne for his contribution to Permian-Triassic research (Gaillot, J., & Vachard, D., 2007).
5. Thomas Bruehwiler, a specialist in Triassic ammonoids, dedicated the species *Parananites baudi* (Fig. 38) as a token of his research in Oman (Brühwiler et al., 2012).

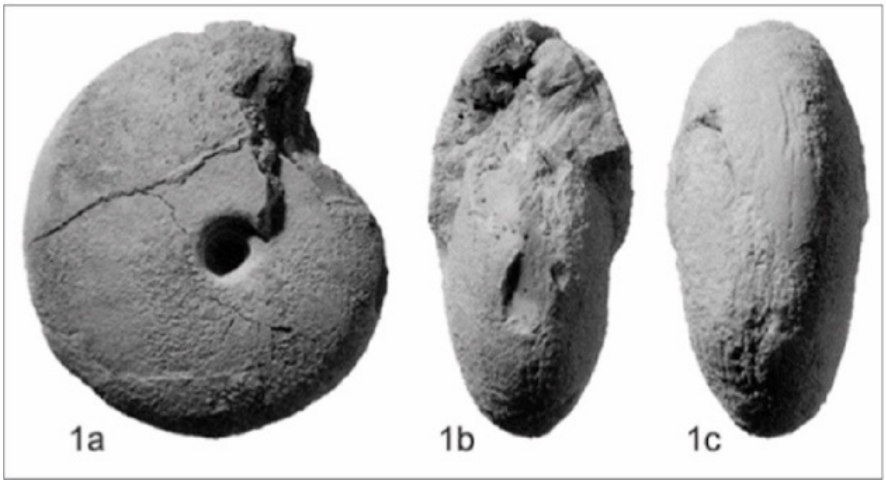

Figure 38 : The new species *Paranannites baudi* (figure 1 from Bruehwiler et al., 2012).

5.14 – Contribution to the History of Geological Science

Given that I was interested in the life of the first Professor in Geological Science at the University of Lausanne, I wrote a historic article on "L'enseignement académique de la géologie à Lausanne de 1832 à 1906 : Eugène Renevier et les naturalistes géologues" (Baud, 2019).

Interested in the history of the study and discoveries of the global marine Permian-Triassic boundary sections, I wrote "Over a century of adventures and controversies". At the global summit on P-Tr mass extinction and catastrophic climate change held in Wuhan, I wrote an abstract (Baud, 2013b) and I published the 21-page narrative in Albertiana (Baud, 2014).

At the HKT 2018 meeting in Lausanne I had the opportunity to make a review on geological research results of the Lausanne team in Himalaya and Tibet before 1988, give a talk, sent an abstract and a poster (Baud, 2018c). I got the opportunity to review the geological research results of the Lausanne team conducted in the Himalaya and Tibet prior to 1988.

5.15 – Tribute to deceased colleagues

In chapters 4.3 and 4.4, I present tributes to my friend and colleague Jean Marcoux.

I have been sharing fieldwork and adventures related to the Subcommission on Triassic Stratigraphy (STS) with Edward Timothy Tozer (1928–2010) for about 30 years. For this reason, in 2012, I wrote an illustrated report of our meetings (Baud, 2012a).

After learning of the passing in 2012 of Professor Emeritus Augusto Gansser (1910–2012) of Zurich, with whom I had the pleasure of interviewing in 2002, I chose to pen a brief biographical note about his remarkable career (Baud, 2012b).

When I discovered at the end of 2017 that my friend and colleague, Professor Emeritus Maurizio Gaetani (1940–2017) of Milano, had passed away, I published an illustrated tribute to him (Baud, 2018d), as well as in the HKT poster.

I was shocked to learn of Professor Michaela Bernecker's unexpected death on November 3, 2017, having worked and published with her at GuTech, a German university in Oman. Along with Dr. Oliver Weidlich, we wrote a piece about the amazing teacher, scientist, and friend Michaela Bernecker (1963-2017) in (Weidlich & Baud, 2019).

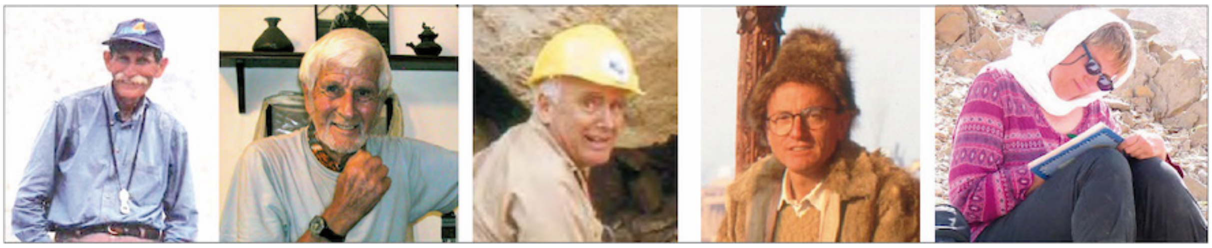

Figure 39 : From left to right : Jean Marcoux, Augusto Gansser, Edward Timothy Tozer, Maurizio Gaetani and Michaela Bernecker.

Conclusions and acknowledgments : the end of the Sinergia program (Paleo C4) and the "Across the End Permian Great Extinction" conference from August 30 to September 2, 2023, in Lausanne

The study of post-extinction microbialite was successfully applied in South China, where it introduced the idea of sponge-microbial buildups. It was also examined in Lower Triassic sections in Central and North Iran, and it was discovered in new sections of Armenia that had enormous sponge-microbial buildups (Baud 2023).

Field study of the Batain area of SE Oman with H.Bucher's research team led to the discovery of numerous fossil-rich blocks and of unknown Lower Triassic reefs, which greatly expanded the research line on basal Triassic quick recovery.

The paleontological study of collected samples in Zurich Paleontological Institute and Museum realized by the PhD students, assistants and professors offers more precise view on the stratigraphic age and facilitates greatly the correlation between distant Permian and Triassic basins.

The geochemical study of collected samples in UNIL's labs, realized by the PhD students, opened new approaches to the Permian-Triassic paleoenvironments.

My involvement in the Sinergia research program from the Universities of Zurich, Lausanne and Geneva has led me to collaborate with Professors Hugo Bucher, Torsten Vennemann and their PhD students (now Doctor of Science) Morgane Brosse, Marc Leu, Zoneibe Luz, Franziska Blattmann and Oluwasser Edward, as well as with Dr. Christian Vérard at the University of Geneva.

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Abstracts of the congress

with some extended abstracts and texts

Coupling timing and tempo of volcanism with the mass extinctions through mercury and tellurium anomalies

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Mercury (Hg) and more recently tellurium (Te) are indicator of large-scale volcanism in marine sediments and provide valuable insights into relative timing between biological and environmental changes, mass extinctions and delayed recovery. Numerous studies have explored the connection between sedimentary Hg anomalies and Large Igneous Province (LIP) activity during mass extinction events (e.g., end-Devonian, Permian-Triassic, Triassic-Jurassic, and Cretaceous-Paleocene extinctions). This presentation will specifically focus on the Deccan volcanism, which is considered a key driver of the KPg mass extinction, alongside the Chicxulub impact. The bulk (80%) of Deccan Trap eruptions occurred over a relatively short time interval in magnetic polarity C29r. U-Pb zircon geochronology reveals the onset of this main eruption phase 350 ky before the Cretaceous-Tertiary (KT) mass extinction. Maximum eruption rates occurred before and after the K-Pg extinction, with one such pulse initiating tens of thousands of years prior to both the bolide impact and extinction, suggesting a cause-and-effect relationship. We present a comprehensive high-resolution analysis of Deccan Traps Hg-Te loading, climate change and end-Cretaceous (KPB) mass extinction from a transect, which includes 30 sections deposited in both shallow and deep environments located in France, Spain, Italia, Denmark, Israel and Tunisia. In all sections, our findings indicate that Hg concentrations are more than 2 orders of magnitude greater during the final 100ky of the Maastrichtian up to the early Danian P1a zone (first 380 Ky of the Paleocene). Notably, Hg anomalies generally show no correlation with clay or total organic carbon contents, suggesting that the mercury enrichments resulted from higher input of atmospheric Hg species into the marine realm, rather than being driven by organic matter scavenging and/or increased run-off. Significant and coeval Hg enrichments are observed in multiples basins characterized by proximal and distal, as well as shallow and deep-water settings, supporting a direct fallout from volcanic aerosols. Hg isotope data from Bidart (France) confirm a direct Hg fallout from volcanic aerosols. Furthermore, Te/Th ratios measured in the Goniuk (Turkey), Elles (Tunisia), Gubbio (Italy) and Wadi Nukhul (Egypt) sections show the same trend as Hg/TOC and are consistent with a volcanic origin, albeit a minor extraterrestrial contribution of Hg at the boundary cannot be excluded. Hg and Te maximum loadings coincide with time of maximum Deccan emission rates and volumes determined by zircon dating. Hg and Te concentrations within sediments in conjunction with Te/Th and Hg/TOC ratios are therefore robust and useful proxies to trace intensity of volcanism. These observations provide further support that Deccan volcanism played a key role in increasing atmospheric CO_2 and SO_2 levels that resulted in global warming and acidified oceans, increasing biotic stress that predisposed faunas to eventual extinction at the KTB

Taxonomic homogenization of marine ecosystems after the end-permian mass extinction was physiologically controlled

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In the wake of the end-Permian mass extinction, global terrestrial and marine ecosystems were depleted in taxonomic diversity and became more cosmopolitan. The causes of the diversity decline are increasingly understood but the explanation for taxonomic homogenization across space remains incompletely known. Here, we quantify changes in cosmopolitanism within the marine fauna across the Permian/Triassic boundary using three measures of taxonomic similarity : Biogeographic Connectedness, Jaccard Similarity and the semimetric Czekanowski's coefficient, each of which measures the degree of taxonomic similarity on a scale from 0 (totally endemic) to 1 (globally widespread). For our analysis, we downloaded fossil occurrence data for classes Bivalvia and Gastropoda spanning the Changhsingian (~254.4 - 251.9 Ma) and Induan (~251.9 -251.2 Ma) ages from the Paleobiology Database (2,140 occurrences of 240 genera) and grouped the occurrences into a global grid of 812 equal-area (~630,000 km^2) hexagonal cells. All three measures indicate that taxonomic similarity increased after the end-Permian mass extinction that persists even after accounting for the geographic distribution of available data. We further divided our dataset by survival status (victims, survivors, and originators). We find a greater degree of provinciality in victims than in survivors during the Changhsingian. However, the increase in similarity between the Changhsingian and Induan is much larger than the difference between victims and survivors within the Changhsingian data, indicating further biogeographic response within surviving genera. Genera that originated in the Induan had similarity indices similar to survivors during that age. Comparison of Permian/Triassic biogeography with environmental changes indicated by paleoceanographic models has the potential to further determine whether the taxonomic homogenization of the oceans was controlled by ecology, environment, or both.

Changes in sedimentation across the Permian-Triassic transition: record from the Saiq formation, Oman

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A new stratigraphic record (~150 m thick) is introduced for the Permian-Triassic transition from previously unexplored sections of the Saiq Formation in Wadi Mijlas and nearby exposures of the Saih Hatat culmination, Oman. The succession reveals previously undescribed sedimentary features and demonstrates a significant shift in depositional processes, biota, and sedimentation patterns across the Permian-Triassic transition. Towards the late Lopingian, the record is dominated by m-scale shallowing-upward cycles within a Highstand Systems Tract, with oolitic facies at the top of each cycle. The sequence boundary is placed at the top of the last bioclastic oolitic grainstone. Carbon isotope ($\delta^{13}C$) values remain steady at ~4%–5% throughout the interval. This unit is overlain by a Transgressive Systems Tract of cm-scale, coarse-grained amalgamated beds with either normal grading or massive textures with erosive bases, inferred to be proximal tempestites. Intervals of wackestone-packstone interbedded with inferred tempestites with occasional hummocky cross-stratification and bioturbation follow, accompanied by a gradual decline in $\delta^{13}C$ values from ~4% to ~2.7%. In the upper part of this unit, there is a notable increase in heterozoan biota, such as sponges, bryozoans, brachiopods, and crinoids. At the Permian-Triassic transition a remarkably distinct ~20 m thick unit of yellowish, cyclic, turbidite-like cm-scale calcisiltite beds appears, which generally lacks fossils and contains disrupted slide-slump structures, but with rare ammonoids, bioturbations and reworked bivalve shells at the top part. While the transition is generally abrupt, some localities show an intraformational breccia comprising reworked cobbles-sized calcisiltite intraclasts. This interval shows an initial negative $\delta^{13}C$ excursion to -0.2%, followed by a short rebound peak of ~1.5%, then gradually decreasing values to -4%. Integrating changes in sedimentation with biota implies a change through the Permian-Triassic transition from mid-outer ramp to slope deposits. The abrupt transition along the boundary highlights a rapid change in depositional setting. We interpret this shift in sediments to be coupled with rapid sea level rise, and so argue that a regression event is not present across this Permian-Triassic transition.

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Redox conditions in Upper Permian and across Permian-Triassic boundary deposits of the Ali Bashi and Zal sections in NW Iran

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Abstract: Anoxia is considered as one of the main causes of mass extinction before Permian-Triassic boundary. In this study redox conditions of Upper Permian shales of the Ali Bashi and Zal sections in SW Iran have been evaluated using redox-sensitive trace elements in order to examine the geochemical status of the seawater during Late Permian as well as before and after extinction horizon. According to V/Cr and V/(V +Ni) ratios the redox conditions throughout Upper Permian successions in both sections change from oxic/dysoxic to suboxic. In the uppermost Changhsingian Aras Member which is located immediately after extinction horizon the increase of these aforementioned rations are evident. The Mo/U authigenic ratios in both sections demonstrate their lower values than Mo/U molar ratio of seawater (~7.5-7.9). The MoEF and UEF covariate plots show the position of samples of two study sections in oxic/dysoxic to suboxic zones. Considering the obtained results, although there is evidence of low oxygen conditions in some parts of the Upper Permian deposits, the lack of oxygen did not happen in extinction horizon and even in the Aras Member there was a suboxic status. Therefore, other mechanisms should be investigated for the low faunal diversity of the Upper portion of the Upper Permian deposits of the Ali Bashi and Zal sections.

1 – Introduction

Permian-Triassic transition defines the severest Phanerozoic mass extinction with more than 92% of marine and land species which was followed by relatively slow recovery during Early Triassic (Erwin, 1994 ; 2006). While extinction in Permian-Triassic boundary has been widely studied but the causes of this extinction is still remained unknown. The anoxic ocean (Wignall and Hallam, 1992; Isozaki, 1994; Erwin et al., 2002; Cao et al., 2009; Brennecka et al., 2011) and large-scale volcanic eruptions (Courtillot, 1999; Bond et al., 2014) are among the significant causes of end-Permian mass extinction. The concurrency of Siberian volcanism and end-Permian mass extinction have been noted in many studies (Renne and Basu, 1991; Reichow et al., 2002; Courtillot and Olson, 2007; Svensen et al., 2009; Burgess and Bowring, 2015; Burgess et al., 2017). The entrance of large amounts of CO_2 and methane to atmosphere is supposed to have been given rise to global warming (Joachimski et al., 2012; Chen et al., 2013; Bond et al., 2014; Saitoh and Isozaki, 2021) and also the acidification of ocean (Fraiser and Bottjer, 2007; Payne at al., 2007; Clarkson et al., 2015; Bond and Grasby, 2017). Penn et al. (2018) suggested the temperature-dependent hypoxia as the main cause of the end-Permian extinction. In recent years, pervasive studies have been carried out on redox conditions as main driver of biotic crisis at the end of Permian but the starting time and the intensity of anoxic oceanic conditions are not clear and needs more research (Ehrenberg et al., 2008; Algeo et al., 2010; Shen et al., 2012; Yano et al., 2020). The Ali Bashi and Zal sections in Julfa area, NW Iran are well-known sections in global scale with having continuous succession of Permian-Triassic (Arefifar and Baud 2023) which are suitable to study end-Permian redox conditions (Fig. 1). In previous studies, a high oxygenated conditions have been suggested for Permian-Triassic boundary for both Abadeh and Julfa sections based on some evidence such as red shales and limestones, high bioturbation and diversity of macro- and microfossils (Heydari et al., 2000; Kozur, 2007; Leda et al., 2014).

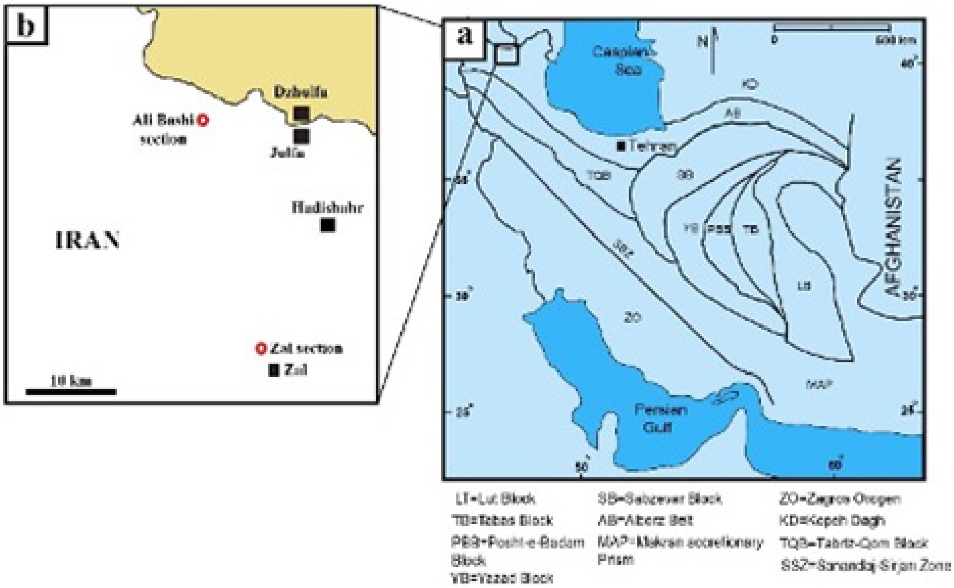

Figure 1- (a) the tectonic map of Iran (adapted from Alavi, 1991),

(b) the geographic location of the studied section.

On the other hand, the results from $\delta^{13}C_{carb,}$ $\delta^{87}Sr/\delta^{86}Sr$ and $\delta^{34}S$ analyses from upper Changhsingian and lower Triassic deposits of Abadeh section showed the existence of the anoxic condition (Korte et al., 2004). The consequences of Schobben et al. (2015) studies in both Ali Bashi and Zal sections using $\delta^{34}S_{CAS}$ (Sulfur isotope in carbonate-associated sulfates) and $\delta^{18}O_{CAS}$ (Oxygen isotope in carbonate-associated sulfates) did not reveal any evidence of anoxic condition before extinction horizon, however they suggested the start of the anoxic condition at extinction horizon. Zhang et al. (2016) examined the $\delta^{238}U$ changes across the uppermost Changhsingian through Lower Triassic strata in Zal section which shows a negative shift for $\delta^{238}U$ starting definitely from uppermost Changhsingian Aras Member immediately after extinction horizon. The redox conditions during Late Permian and before end-Permian extinction in Julfa sections have not been pointed out in none of the previous studies. In this research, we try to evaluate the geochemical features of sea water during Late Permian and across Permian-Triassic boundary using redox-sensitive rare elements such as U, Mo, V, Cr and Ni. The results of this study will also enable us have better understanding of presence or absence of anoxic conditions in the end-Permian extinction in two well-known Ali Bashi and Zal sections. In both Ali Bashi (61.5 m thich) and Zal (59.5 m thick) sections, Upper Permian deposits include Wuchiapingian Julfa Formation (35.5 m thick in Ali Bashi section and 34 m thick in Zal section) and Changhsingian Zal Formation (23.5 m thick in Ali Bashi section and 21 m thick in Zal section). The Julfa Formation is subdivided into lower and upper parts named as Lower Julfa Beds (20.5 m thick in Ali Bashi section and 22 m thick in Zal section) and Upper Julfa Beds (15 m thick in Ali Bashi section and 13 m thick in Zal section). The Ali Bashi Formation is divided into Changhsingian Zal Member (19 m thick in Ali Badhi section and 17 m thick in Zal section), upper Changhsingian Paratirolites Limestone (4.5 m thick in both Ali Bashi and Zal section) and uppermost Changhsingian Aras Member (0.5 m thick in both Ali Bashi and Zal sections) which are overlain conformably by Lower Triassic Elika Formation. The Lower Julfa Beds are composed alterations of grey shales and thin- to medium-bedded limestones. In Upper Julfa Beds, the red to pink limestones are dominant lithology with some red shaley alterations in lower and middle parts. Zal Member is characterized by red shales with low few alterations of red to purple limestones with are overlain by cliffy red nodular Paratirolites Limesones. The

Aras Member or Boundary Clay includes greenish to light gray shales overlain by platy limestones of Lower Triassic Elika Formation. Based on recent studies the extinction horizon in both Ali Bashi and Zal sections is located immediately below sponge packstone at the topmost part of the Paratirolites Limestone and below Aras Member (Leda et al., 2014).

2 – Methods and Materials

For this study shaley samples from Julfa Beds, Zal Member and Aras Member in both Ali Bashi (21 samples) and Zal (35 samples) sections for rare elements measurements and analyses were chosen. First, the samples were crushed in a mortar to sizes smaller than 200 mesh and then dried at 60 °C to keep their weight constant. The process of pulverizing the samples was done in the geological laboratory of Lorestan University. To determine the trace elements, in the first dissolution step, 0.04 g of samples powder was dissolved in 6 mL of N HF/6 N HNO3 (1 :2) at 220 ºC for 24 h and dried. Then, the samples were cooled at room temperature and taken up in dilute HNO3 and further diluted with ultrapure H2O to a volume of 100 mL to be ready for reading by ICP-MS. After the initial measurement of the concentration of the elements by the devices, the raw data were converted into known concentrations and processed.

3 – Discussion and results

Examining the graphs related to oxidation and reduction indicators against stratigraphic columns shows the changes of oxidation and reduction values during the deposition of Upper Permian shales of two Ali Bashi and Zal sections (Fig. 2). Upper Permian sediments in the two sections studied generally indicate conditions from oxic-dysoxic to suboxic. The increase of U/M and V/(V + Ni) values in Aras Member in both Alibashi and Zal sections indicates the better enrichment of uranium in suboxic conditions. Values of V/Cr less than 2 and V/(V + Ni) less than 0.53 in of Jones and Manning (1994) are considered as oxide conditions, which do not match the data of this study. Therefore, in order to better match the zoning with the Mo_{EF} versus U_{EF} diagram, values of V/Cr less than 2 and V/(V + Ni) less than 0.53 are suggested as oxic-dysoxic conditions. Also, values of V/Cr greater than 2 and V/(V + Ni) between 0.53 and 0.6 are considered as suboxic conditions for both Ali Bashi and Zal sections. The patterns of simultaneous changes between molybdenum and uranium in ancient and modern marine systems have always been of interest (Algeo and Manyard, 2004 ; Algeo and Tribovillard, 2009 ; Tribovillard et al., 2012). The sensitivity of molybdenum and uranium to oxidation and reduction conditions is higher compared to other indicators and they are especially useful for the analysis of ancient environments. Both of these elements are present in small amounts in the upper continental crust (on average, molybdenum is about 3.7 ppm and for uranium is about 2.7 ppm, Taylor and McLennan (1985)). Furthermore, Both Mo and U behave normally in oxide conditions and have long lifetimes in seawater (450,000 years for uranium and 780,000 years for molybdenum). On a global scale, the Mo/U molar ratio is 7.35 in the Pacific Ocean (Millero, 1996) and 7.90 in the Atlantic Ocean (Chen et al., 1986). Both of these elements are low in planktons and therefore, their enrichment in sediments or sedimentary rocks is usually attributed to the authigenic absorption of these elements from sea water (Algeo and Tribovillard, 2009). Despite these similarities, important differences are seen in the behavior of molybdenum and uranium under reduction conditions, which causes differences in their abundance in marine sediments. Authigenic uranium absorption starts at the limit of Fe (II) reduction to iron (III) (Zheng et al., 2002a,b), while authigenic molybdenum absorption occurs later because it requires the presence of hydrogen sulfide (Zheng, 2000). The relationship between oxidation and reduction conditions with in-situ enrichment of molybdenum-uranium is such that in open marine systems with molybdenum and uranium oxide facies, there is no enrichment, and their enrichment factor is less than 10 (Algeo and Liu, 2020). In suboxic facies, molybdenum and uranium enrichment is moderate, and uranium enrichment is more than molybdenum enrichment, because uranium absorption takes place at the border of reduction of Fe (II)to Fe (III), and as a result, the Mo/U authigenic ratio is significantly lower than the Mo/U molar ratio of seawater, which is 7.5 to 7.9 (Morford et al., 2005). In anoxic conditions, enrichment of uranium and molybdenum is intense, which is accompanied by high Mo/U authigenic ratios and is higher than the Mo/U molar ratio of seawater (Morford and Emerson, 1999; Algeo and Tribovillard, 2009).

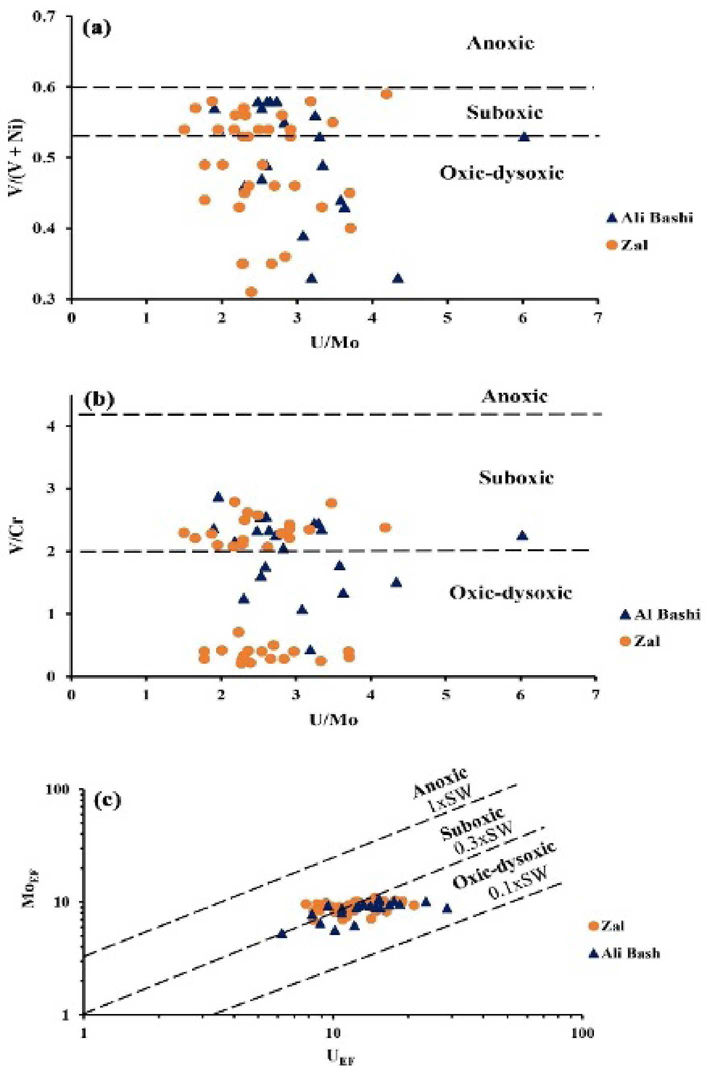

Figure 2. Comparison of U/Mo ratio (adapted from Jones and Manning, 1994) and redox chemical indicators including V/(V + Ni) (adapted from Hatch and Leventhal, 1992) and (b) V/Cr (adapted from Jones and Manning , 1994) and also (c) the diagram of MoEF versus UEF (adapted from Wignall and Myers, 1988) which shows the location of samples of Ali Bashi and Zal sections in oxic to suboxic range and does not show anoxic conditions. Dashed lines in C show Mo/U molar ratios equal to the seawater value (1×SW) and to fractions thereof (0.3×SW, 0.1×SW).

4 – Conclusion

In order to investigate the conditions of oxidation-reduction conditions and geochemical changes of sea water before and after the end-Permian extinction horizon, the Upper Permian deposits of the Ali Bashi and Zal sections were studied in Julfa area in the northwest of Iran. For this purpose, changes of trace elements sensitive to oxidation and reduction conditions in Upper Permian shales in two sections studied have been used. The values of V/Cr and V/(V+Ni) ratios indicate the change of oxidation and reduction conditions from oxic/dysoxic to suboxic and even in Aras Member (Boundary Clay) which is located after the extinction horizon, the values of these ratios do not support the anoxic condition. Examining the U/Mo ratio throughout the Upper Permian sequences shows the relatively high uranium content and the creation of suboxic conditions in some layers. The authigenic Mo/U ratio in all samples is lower than the Mo/U molar ratio of seawater (7.5 to 7.9) and the analysis of the Mo_{EF} versus U_{EF} diagram shows that the studied samples are in oxic/dysoxic to suboxic conditions. The previous data about the ancient climate conditions in the Upper Permian deposits in Ali Bashi and Zal sections, based on the amount of oxygen isotope changes in conodonts, confirm the beginning of water warming in the Aras Member (Boundary clay), which is located after the end-Permian extinction horizon. According to the results obtained from this study, it can be concluded that faunal diversity decrease at the end of Permian in the studied area was not caused by the anoxic conditions and therefore it might be triggered by other factors.

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Six main facies in the post-extinction basal triassic (griesbachian) of Oman, from deep to shallow and from euxinic to well oxygenated

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This short sedimentological approach results from field works done first with Lausanne and later Zurich PhD plus PostDoc students and paleontologists, with colleagues from France, Austria, Italy, and Canada.

During the Permian-Triassic transition (PTt) the calcite compensation depth (CCD) is marked by a rise from deep to shallower depth in the paleo-oceanic Buda'yah section (Baud et al., 2012), showing a basal Triassic facies of light calcareous shale and platy lime mudstone beds overlying dark late Permian radiolarite chert beds and siliceous shales. The platy lime mudstone beds include an Upper Griesbachian bloom of calcite filled spheres (radiolarians ?) that marks a potential world-wide event.

The next main facies occur on the continental-slope deposit of the Wadi Maqam section (Richoz et al., 2010, 2012) where we observe the same CCD rise, here from chert bands in Late Permian dolomite beds to 3 m thick boundary calcareous shales and up to 9 m of basal Triassic laminated papery limestones and stromatolite deposits in euxinic environment.

If apparently continuous deposits during PTt occur on shallow continental margin cropping out in the autochthonous, dolomitized Permian-Triassic water carbonate succession, gaps are present in the Saih Hatat (Weidlich & Bernecker, 2011) as in the Djebel Akhdar (North Oman mountains). The main basal Triassic facies on the Saiq Plateau sections consists of light thin bedded dolomudstone overlying brown azoique dolomudstone with disrupted and deformed beds (seismite, described in Baud et al., 2016).

During Triassic and Lower Jurassic times the Hawasina and Batain basins have been the sites of large-scale debris flows and olistostromes. Within the great number of reworked blocks, the discovery of basal Triassic highly fossiliferous boulders, revealed three new facies of Griesbachian limestones built, for two of them, by skeletal accumulations in well oxygenated water. These facies are in marked contrast with the euxinic muddy carbonate (dolomudstone) of the shallow water platform sediments. Their origins are from seamount or oceanic plateau, above fair-weather wave base.

The first of these three facies consist of a bivalve bioherm overlain by a Bivalve biostrome with rare Brachiopod, Gastropod and a new type of Crinoid, well dated by conodonts and characterize the Griesbachian Wasit block facies described by Krytsyn et al., (2003) and Twitchett et al., (2004). A similar Griesbachian coquina facies occur in the not yet described Naksi block in the Wadi Wasit and another coquina block in the Asselah area (Batain).

The second facies is a crinoidal lime-packstone discovered in an Asselah block described by Brosse et al. (2018) and showing among crinoids a rich assemblage of bivalves, gastropods and ammonoides.

The third facies show for the first-time a stromatactis pelagic Hallstatt-type limestone of Griesbachian age. It has been discovered by H. Bucher in a 30m thick reworked block (RAA) comprising Late Permian and Early Triassic carbonate succession in Djebel Rabat. After a preliminary sedimentological study, it is interesting to note the disrupted and deformed beds at the Permian-Triassic contact due to possible seismite.

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Carboniferous-Permian low latitude glendonites: a record of episodic upwelling in aragonite seas

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Ikaite ($CaCO_3.6H_20$) is a hydrated form of calcium carbonate mineral that grows in a variety of shapes at, or immediately beneath, the sediment-water interface in marine to non-marine environments. Ikaite grows as individual crystals or as variety of 2D and 3D arrangements of crystals, the most common of which are referred to as "hedgehogs". Individual ikaite crystals display quasi-square transverse sections, and when well-preserved, bi-pyramidal oppositely canted crystal terminations, two "smoking gun" criteria indicative of its monoclinic crystal structure, which sets it apart from anhydritic forms of calcium carbonate. Ikaite is widely viewed as precipitating exclusively in near-freezing temperatures (1–7 °C) in cold climatic or oceanographic settings. Other conditions deemed necessary for ikaite growth, based mostly on laboratory experiments, are high alkalinity, provided in the environment by decaying organic matter, oxidation of seeping methane, or spring discharge, and the presence of an inhibitor of anhydritic calcite, such as orthophosphate, to prevent the thermodynamically favoured growth of low Mg calcite. Ikaite is inherently unstable and will quickly disintegrate when subjected to higher temperatures and will thus leave no trace in the rock record. However, given the right environmental and diagenetic conditions, ikaite transforms itself into a pseudomorph called glendonite, which maintains the megascopic and crystallographic shape of ikaite, while slowly dehydrating to calcite. The best preserved, and most abundant, glendonites in the rock record occur in high latitude areas, such as in the Cretaceous of Arctic Canada (75–80°N). Here, glendonites comprise a variety of well-preserved low Mg calcite phases that recorded the early transformation of ikaite to glendonite within the upper portion of the sedimentary column, and subsequent burial to a significant depth. Upper Paleozoic glendonites are also known from considerably lower paleolatitudes (~5–20°). These include typical glendonite rosettes and "hedgehogs" from: Lower Carboniferous of Alberta, Canada; Upper Carboniferous of Nevada, USA; Lower Permian of South China and New Mexico, USA; and the Middle Permian of Turkey and Oman. Albeit often smaller than their high latitude counterparts, these glendonites display the telltale signs of their monoclinic precursor ikaite, but they are variably preserved as complex arrangements of early to late diagenetic infills, including calcite, quartz, gypsum, anhydrite and, in some cases, celestite. The South China, New Mexico and Oman examples were studied in detail where the growth of ikaite on the sea floor was intimately linked to short-lived episodes of upwelling as shown by the replacement of prolific warm water photozoan carbonates by cool to cold water heterozoan carbonates. As best exemplified in Oman, episodic upwelling occurred at a frequency of ~500–2000 years, indicating some form of millennial climatic or oceanographic fluctuations that may be associated with recurring variations in the intensity of the mega-monsoonal system prevailing at that time. That said, the presence of glendonites at low-latitudes is problematic as modern upwelled water along low-latitude oceanic margins is rarely cooler than 10–15°C, which suggests either one of two things: the vertical thermal structure of late Paleozoic oceans may have

been different than that of the modern oceans, or ikaite can form in considerably warmer waters than generally assumed, both of which have been suggested by some authors. Noteworthy, none of these low latitude glendonites are associated with high concentrations of either organic matter or phosphate. While the necessary high alkalinity may have been provided by the early dissolution of unstable carbonate minerals (e.g., aragonite), the low Mg calcite inhibition may have been provided by the high Mg/Ca ratio in the oceans, which is held responsible for the low-latitude aragonite sea that prevailed in the late Paleozoic. Low temperatures and high Mg/Ca would have worked in concert to inhibit authigenic low Mg calcite growth during the upwelling episodes, thus allowing ikaite to grow.

Rapid environmental improvement following latest permian mass extinction in mid-latitude Sverdrup basin (arctic Canada)

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One of the most widely accepted views about the Latest Permian Extinction (LPE) and its aftermath is that environmental mayhem and biological devastation occurred rapidly and endured for millions of years afterward well into the Early Triassic. The paleontological and sedimentological record of low latitude areas (e.g. peri-Tethys) supports that claim as shown, for instance, by the rapid eradication of prolific carbonate factories and their replacement by microbial communities. However, sediments that accumulated in the wake of the LPE at mid-latitudes, such as in the Sverdrup Basin, Arctic Canada, tells a much different story.

The Sverdrup Basin was located along the northwest margin of Pangea at ~40-45°N during the Late Permian-Early Triassic transition. Earlier in that area, healthy Early Permian photozoan carbonate factories gave way to Middle and Late Permian impoverished heterozoan factories that became increasingly less productive and were progressively replaced by hyalosponge factories. By Wuchiapingian (Late Permian) time, carbonates were all but eradicated from the Sverdrup Basin and spiculitic chert occupied the entire spectrum of shallow to deep, inner to outer ramp environments. This has been explained by ocean acidification, fuelled by massive CO_2 increase in the atmosphere and enhanced by upwelling, which led to shallow water areas falling below aragonite and calcite saturation. Only those organisms (siliceous sponges, phosphatic brachiopods) that could thrive in lower pH waters became preserved in widespread chert blankets that extended from the western USA to the Barents Sea (Permian Chert Event).

Wuchiapingian calcite-secreting brachiopods and bryozoans are extremely rare and corroded to varying degrees, while aragonite-secreting ammonites have never been observed. Conodonts too suffered major losses as only two long-ranging species (Mesogondolella rosenkrantzi and M. sheni) are known from chert-dominated successions. Furthermore, widespread anoxia started developing in the Late Permian, first in the deep axial area of the basin, but rapidly encroaching upon shallower ramp areas. By the early Changhsingian, anoxic, and even euxinic, conditions were established in all but the shallowest nearshore areas of the Sverdrup Basin. This led to even more biological devastation, as seen by a net reduction, and then virtual end, of bioturbation. It is important to note that this environmental devastation occurred BEFORE the latest Permian extinction event, which, contrary to generally held beliefs, led to a geologically instantaneous improvement in environmental conditions at mid-latitudes. This is shown by exceptional beds on NW Ellesmere Island that preserve a latest Permian (post-extinction/pre-Triassic) record at a time when clastic sedimentation was not quite established yet. These beds provide evidence for : 1) return to carbonate production ; 2) near complete cessation of chert accumulation, heralding the Early Triassic Chert Gap ; 3) re-establishment of bryozoan populations ; 4) return of widespread bioturbation and production of faecal pellets ; 5) deepening of the oxygen-minimum zone down to at least the basinal edge of the outer ramp ; 6) incursion of large number of spherical radiolarians ; 7) net reduction in the number, length and diameters of sponge spicules ; 8) invasion and preservation of aragonite-secreting ammonites (e.g.

Otoceras concavum, O. boreale) ; and 9) incursion of a diversified conodont fauna of tropical affinity, including several species of Clarkina. Clearly, environmental conditions improved on the mid-latitude shelves of northwest Pangea (much warmer, better oxygenized, less acidic waters) in the immediate aftermath of the LPE. Favourable conditions for marine life persisted well into the clastic-dominated Early Triassic as shown by widespread bioturbation, locally rich bivalve and bryozoan fauna, and diverse ammonite (e.g. Otoceras commune) and conodont (e.g. Hindeodus parvus, Clarkina spp.) populations. Clearly, the mid-latitude shelves of NW Pangea must have offered a refuge for benthic and pelagic/nektonic organisms at a time when extreme post-extinction conditions prevailed at low latitudes.

Examining carbon cycle perturbations during the Smithian-Spathian in central Spitsbergen

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The Smithian-Spathian boundary represents a critical time interval in the Early Triassic as it follows the largest mass extinction in Earth's history. This interval is characterized by global carbon cycle disturbances, decreasing sea surface temperatures, high turnover rates of marine nekton, and large shifts in terrestrial vegetation communities (Brayard et al., 2011 ; Goudemand et al., 2019 ; Schneebeli-Hermann et al., 2012 ; Widmann et al., 2020). Despite the geological importance of this epoch, comprehensive investigations focusing on multiproxy analysis from high latitude regions during the Early Triassic have been limited. Here we reconstruct local-to-regional dynamics of the carbon cycle alongside co-occurring paleoenvironmental change amid the Smithian and Spathian in a high latitude section from Spitsbergen. Our results suggest fluctuations in ocean oxygenation (oxic/anoxic) conditions throughout the Smithian and Spathian. Anoxia have also been noted for other Arctic basinsduring the same time interval, supporting a broader regional paleoenvironmental development (Grasby et al., 2013 ; Hansen et al., 2018). Anoxic bottom-water conditions would have promoted the preservation of organic matter and likewise restricted phosphorus remineralization, facilitating its recycling within the water column possibly influencing primary productivity. Coincident fluctuations in isostatic and eustatic sea levels likely played a role via influences on organo-mineral interactions, which in turn modulate organic carbon sequestration (Bianchi, 2011 ; Kennedy and Wagner, 2011). Based on the findings of this study we conclude that local organic carbon sequestration on the Barents Sea shelf was likely influenced by a combination of different factors, including sedimentology, redox conditions, nutrient availability, and primary productivity.

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Late Permian – early Triassic non-marine record in western tethys, climatic implications

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The aim of this presentation is to review our knowledge of the East Pangean intertropical domain from the end of the middle Permian to the middle Triassic, based on sedimentological data and paleoenvironmental reconstructions. In European and North Gondwana domain an angular unconformity is observed between deposits of the upper Permian and Triassic, except in the central part of the Germanic Basin. The sedimentation gap is more developed in the southern area where, in some basins, upper Permian sediment does not occur. At the scale of Europe, the large sedimentary supply, erosion and/or lack of deposition during the late Permian, as well as the variable palaeocurrent direction pattern between the middle–late Permian and the early Triassic indicate a period of relief rejuvenation during the late Permian. During the Induan, the continental area was under erosion and sediment was only preserved in the northern, i.e. the central part of the Germanic Basin, and extreme southern domains. These sediments were preserved under the same climatic conditions as during the latest Permian, whereas in the extreme southern Europe, they were probably preserved in the Tethys Ocean, implying a large amount of detrital components entering the marine waters. The early Triassic sedimentation began with the ephemeral fluvial systems indicate arid climatic conditions during this period. At the top of the early Triassic, another angular unconformity is observed : the intra-Spathian Hardegsen unconformity. This tectonic activity created a new fluvial style, with marine influences at the distal part of the systems. During the Anisian and Ladinian, sedimentation was characterised by the fluvial system evolving into fluvio-marine environments with a direct influence of the Tethys Ocean in the southern and northern domains. Both at the end of the Olenekian (Spathian) and during the Anisian, the presence of palaeosols, micro- and macrofloras indicate less arid conditions throughout this domain. In North Africa, the fluvial sedimentation during the early Triassic occurs in the Tunisian and Libyan basins, and is characterized by coastal plain deposits. In the Algerian Triassic basins, an angular unconformity at the base of the Triassic represents the boundary between pre-Triassic deposits and the middle or upper Triassic sedimentary succession, with lack of early Triassic sedimentation. The early Triassic deposits has been dated in the High Atlas Morocco Basin. In consequence, from a detailed sedimentological study, including palaeosol analysis it has been possible to characterize the beginning of Mesozoic sedimentation in the High Atlas area, which occur in endoreic basins, and to realize a comparison with Europeans basins.

Exceptional and unexpected early Triassic marine assemblages from the western USA basin and south China

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After the Permian-Triassic mass extinction (PTME), early Triassic marine assemblages are usually considered as highly depauperate and poorly diversified, especially benthic communities. The post-extinction biotic recovery was thought to be slow and trophically stepwise. Full re-establishment of complex marine ecosystems was assumed to have not occurred until ~8 million years after the PTME, being represented by the Luoping Biota. The recent discovery of new paleontological localities from the late Dienerian of South China and earliest Spathian of the western USA basin challenges this commonly assumed scenario. These assemblages – respectively the Guiyang Biota and the Paris Biota – unveil a spectacular and unexpected diversity and complexity showing a mix of primitive species from the early Paleozoic and first direct ancestors of modern forms, and indicate the rapid rise of modern-type marine ecosystems after the PTME. The Early Triassic is therefore a crucial interval in the development of modern-type marine ecosystems and these assemblages show key fossils records for the understanding of their establishment. Here we briefly present several new exceptional assemblages of similar or slightly younger age, and geographically distant within the western USA basin, allowing the determination of the spatio-temporal extent of the Paris Biota, as well as environmental conditions that influence its formation and preservation. The Guiyang Biota and the Paris Biota are probably not local exceptions and provide new information on paleobiology, paleoenvironment and the preservation of these organisms. They also question their actual diversity and abundance, which are obviously still largely underestimated although they are key parameters for developing accurate post-crisis rediversification scenarios.

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Oman exotics: new Dienerian, Smithian and Spathian ammonoid faunas

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The presence of early Triassic ammonoids in the Hallstatt-type exotic blocks in Oman has long been known. In 2012 we published a first comprehensive study on the Smithian ammonoid taxonomy and biochronology from Oman. Here we present 4 new blocks that add significantly to the completeness of the Oman Early Triassic ammonoid record.

Block RAA (c. 30m) from Jebel Rahbat spans from the Griesbachian to the middle Smithian. Ammonoid-bearing beds are rare in this block, including three faunas from the middle Dienerian and the early Smithian. Block WAD2 (1.4m) from Wadi Ad Daffa contains a succession of 18 successive ammonoid associations ranging from the early Dienerian to the middle Smithian. Block RAC (2.5m) from Jebel Rahbat yielded three middle Spathian faunas corresponding to the Procolumbites beds and Hellenites beds. Block RAF (1m) from Jebel Rahbat contains several ammonoid-rich beds ranging from the Hellenites beds to the Haugi Zone.

Comparison of the new faunas with other, well-known basins such as South China, the Salt Range (Pakistan) and North America shows that most of the known ammonoid associations occur in the Oman exotics. However, faunas from the latest Smithian and the early Spathian are still missing. Despite low sedimentation rates no evidence of palaeontological condensation has been found. Several new ammonid genera and many new species will be described.

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Insights and perspectives from lipid biomarkers from the Permian/Triassic boundary in Svalbard

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For estimating the magnitude and timing of the end-Permian mass extinction and the subsequent recovery in the Early Triassic, the fossil record provides a well-established source of information. However, while the record of micro- and macrofossils is biased by rarity, changing facies and sampling style, molecular fossils (lipid biomarkers) can complement the fossil data. Molecular fossils from various organisms can be preserved over geological timescales and are used to reconstruct environmental conditions in the water column of paleo-ecosystems (e.g., mode of primary productivity or redox conditions). Here, we analysed molecular fossils from Permian-Triassic sedimentary rocks from Lusitaniadalen, Svalbard, deposited in a boreal shallow marine environment. The studied molecular fossils are well preserved due to low degrees of diagenetic alteration and thermal maturation of the rocks. The total content of the n-hexane-soluble fraction (maltenes) increases more than 10-fold above the extinction horizon, either due to an increase of organic matter deposition from flourishing disaster taxa or improved conditions for biomarker preservation. Indeed, a decrease in the ratio of the chlorophyll-derived regular isoprenoids pristane to phytane (Pr/Ph) from 1.64 to 1.09 during the latest Permian indicates the development of a hypoxic to anoxic water column. This could have enhanced organic matter preservation and is consistent with anoxia as one of the main drivers of the end-Permian mass extinction. The extinction horizon at Lusitaniadalen coincides with a lithological change from fine sandstones to mudstones, potentially introducing a bias to the extinction signal. Interestingly, a similar lithological change is observed in the lower part of the section in the Permian Kapp Starostin Formation. However, changes in the biomarker inventory are apparently not correlated with changes in lithology, supporting the authenticity of the extinction signal. Among the compounds exclusively found in the post-extinction interval is C_{33} n-alkylcyclohexane (C_{33} n-ACH). This compound is produced by an unknown taxon that thrived in the aftermath of the extinction. C_{33} n-ACH is not associated with a certain lithology, and therefore probably represents a marker of post-extinction communities. While C_{33} n-ACH is present in all post-extinction samples, Pr/Ph values, and therefore water column oxygenation state, approach pre-extinction levels of 1.56 about 15 m above the extinction horizon. Therefore, the return to a fully oxic water column during the Early Triassic was possibly pre-dating the recovery of the biological community.

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Marine sulphur isotope records and environmental changes during the Smithian-Spathian transition : insights from nearshore and offshore tethyan successions

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The Smithian – Spathian transition (Early Triassic) was an interval of global marine and terrestrial environmental perturbations in the aftermath of the Permian-Triassic boundary mass extinction. Although documented from several spatially disparate sites, the causal mechanisms of these environmental disturbances remain debated. The current study provides a high-resolution middle Smithian to Spathian sulfur isotope record of carbonate associated sulfate (CAS) from three spatially dispersed marine successions representing deep-water nearshore (Qiakong, South China, PaleoTethys) and shallow-deep water offshore marine environments (Jebel Aweri and Wadi Musjah, Oman, NeoTethys). The aim is to disentangle local versus global controls on marine environmental changes as recorded in the Tethys region and thus, better constrain the causal factors of these perturbations during the studied interval. Results reveal differences in the expression, magnitude, and relative timing of sulfur isotope perturbations between the investigated successions. In contrast with previous studies, a negative $\delta^{34}S$ excursion for both CAS and pyrite is recorded between the middle Smithian to upper late Smithian for Qiakong. This middle Smithian negative $\delta^{34}S$ excursion is not recorded in the NeoTethyan sections. In addition, a pronounced positive $\delta^{34}S$ excursion, coeval with the global positive carbon isotope excursion (CIE) is recorded at the SSB for Qiakong. However, the offshore record displays a gradual positive excursion, with a factor of 3 smaller magnitude, spanning the middle to late Smithian and terminating at the SSB. For all sections, however, the basal Spathian is characterized by a prominent negative excursion, coincident with both climatic cooling and sea level regression. We interpret the variability in expression and magnitude of the recorded sulfur isotope excursions to reflect the influence of local effects on the Smithian – Spathian $\delta^{34}S$ record in nearshore depositional settings. Furthermore, we propose a model whereby increasing marine productivity, eutrophication, oxygen depletion, and enhanced organic carbon and pyrite burial, drove the global S-cycle during the middle Smithian to SSB, as expressed by a global overall positive (ca. 10 ‰) $\delta^{34}S$ trend characterizing this interval. At the same time, the negative middle to late Smithian excursion recorded in the nearshore PaleoTethys section was probably driven by elevated continental weathering fluxes facilitated by regional-scale volcanism. The weathering of buried pyrite in subaerially exposed continental shelves during the SSB and into the earliest Spathian, associated with glacio-eustatic sea-level regression, probably caused the negative $\delta^{34}S$ excursion recorded in the basal Spathian. Thus, although locally outpaced by riverine sulfate input fluxes, globally enhanced pyrite burial and/or microbial sulfate reduction were/was the major control(s) on the global sulfur-cycle until the SSB, after which continental weathering fluxes dominated the global sulfur isotope inventory. These results indicate that distance from the paleo shoreline greatly influences the record of marine environmental change archived in Early Triassic nearshore marine rock successions.

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Late permian / early triassic stress events and permian – triassic boundary in Croatia

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Upper Permian and Lower Triassic deposits are one of the best studied on our planet, and various scientists, by studying these deposits and by determining the Permian–Triassic Boundary (PTB), try to resolve the cause of the biggest mass extinction in the geological history. Several studies in Croatia focused on these, rarely exposed deposits. The main research areas include Velebit Mt. area and Samoborsko Gorje Hills, concerning the PTB, and Muć–Ogorje area in southern Dalmatia where changes in biota, environmental conditions and depositional patterns were studied in the aftermath of the extinction. Presented research focused on sedimentology, palaeontology and stratigraphy of the studied deposits, as well as on the positioning of the PTB using geochemical methods, including stable isotopes of carbonates ($\delta^{13}C_{carb}$, $\delta 18O_{carb}$) and organic matter ($\delta^{13}C_{org}$, $\delta 15N_{org}$), major, trace and rare earth element (REE) compositions and biomarkers.

Keywords : Croatia, Permian, Triassic, PTB, carbonates, clastic deposits

Introduction

End Permian to Early Triassic interval is famous for the biggest mass extinction connected with the Permian–Triassic Boundary (PTB). Therefore, the uppermost Permian and lowermost Triassic deposits, including the PTB interval, have been studied in detail around the globe.

Upper Palaeozoic deposits in Croatia crop out in only 11 geographically restricted areas (Sremac, 2005), while Lower Triassic deposits are more common (Velić and Vlahović, 2009). Nevertheless, the contact between these units is extremely rarely exposed.

The main research area concerning the Permian and Triassic deposits in Croatia includes the inland slopes of the Velebit Mt. (1 in Fig. 1), with carbonate deposits originating from the platform that was established following several tectonically active phases and uplift during the Late Palaeozoic. Particularly well known is a more than 900 m thick Middle–Upper Permian carbonate succession, dominated by alternation of early- and late-diagenetic dolomites, with three distinct limestone zones. Although lithologically rather uniform, frequent subtidal–supratidal cycles can be revealed on the basis of sedimentological and palaeontological features (solution vugs, mud cracks, dolomitization patterns, microbialites etc.). Although biota was gradually changing, several typical microfacies patterns were common during the Middle–Late Permian. The dominant carbonate producers were calcareous algae (dasycladales, gymnocodiaceans), typical for very shallow, restricted subtidal environments, locally in association with large benthic fusulinid foraminifera. Microbial mats were typical for the low-stand episodes (Sremac, 2005). During the Late Permian, low-stand phases became more common, with a dominant regressive event recorded close below the Permian–Triassic boundary. This event finally caused a distinct change in the depositional setting, introducing again the terrestrial input to the platform. All Permian "equilibristic" biota disappeared, while only a small number of opportunistic taxa survived (Sremac, 2005 ; Fio et al., 2010).

The second research area with the Upper Permian and Lower Triassic deposits includes northern part of the Samoborsko Gorje Hills in NW Croatia (2 in Fig. 1) that belong to the Zagorje-Mid-Transdanubian Zone of the Inner Dinarides (Pamić and Tomljenović, 1998). Studied sequence is composed of Upper Permian (Lopingian) carbonates rich in calcareous algae (gymnocodiaceans and dasycladales), gastropods and small foraminifera. The middle part is characterized by the dolomitic breccia and microbreccia, known as "Transitional breccia", with common disaster forms of foraminifera, confirming the environmental crises in the shallow-marine environments and stressful and probably dysoxic environmental conditions during the transgression, followed by the gradual recovery of the biota in Early Triassic (Fio et al., 2013).

The third research area includes Lower Triassic clastic and carbonate deposits of the Muć–Ogorje area in Central Dalmatia (southern Croatia ; 3 in Fig. 1) which were studied in order to explain changes in biota, environmental conditions and depositional patterns after the PTB. Identified fossil and trace fossil associations suggested a Dienerian age for the lower, Smithian for the middle, and Spathian age for the upper part of the studied profile (Fio Firi et al., 2022).

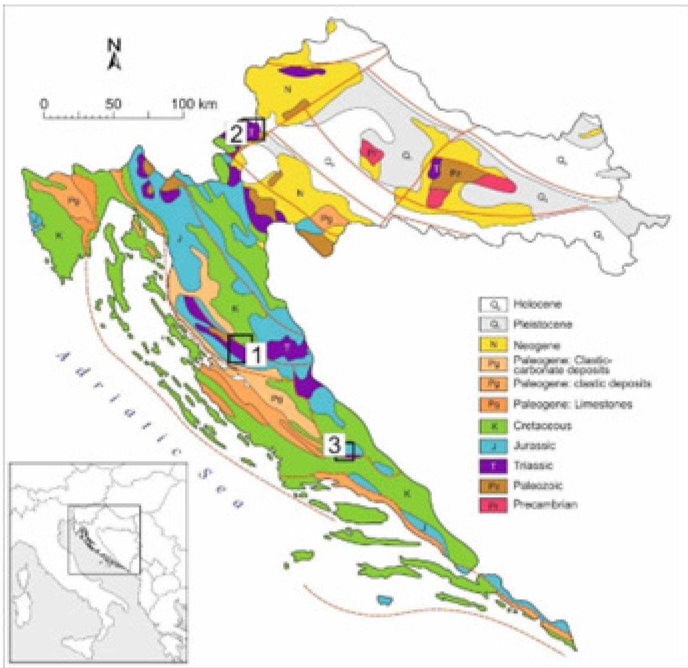

Fig. 1. Simplified geological map of Croatia (modified after Velić and Velić, 1995) with marked position of the study areas : 1) Velebit Mt. in southern Croatia, 2) Samoborsko Gorje Hills in NW Croatia, 3) Muć–Ogorje area, southern Croatia.

Methods and materials

The Permian and Triassic deposits in Croatia were studied throughout the 20th century. We will mention : Salopek (1942, 1948), Sokač (1973), Sokač et al. (1974, 1976), Šikić et al. (1977, 1979), Herak (1983), Šćavničar and Šušnjara (1983), Kochansky-Devidé (1973, 1982), Sremac and Kochansky-

Devidé (1982), who mostly worked in aforementioned main research areas, but also Palinkaš and Sremac (1989) and Sremac and Aljinović (1997) for other areas in Croatia.

During the last 20 years, the research was more intensified through the work done by Jelaska (2003), Aljinović et al. (2003, 2006, 2008, 2018), Sremac (2005), Fio et al. (2010, 2016), Chen et al. (2021) and Fio Firi et al. (2022). Mentioned authors focused on sedimentology, palaeontology and stratigraphy of the studied deposits. The position of the PTB was determined only at two localities in the Velebit Mt. area (Rizvanuša and Brezimenjača), using geochemical methods, including stable isotopes of carbonates (δ1^{3}Ccarb, δ18Ocarb) and organic matter (δ1^{3}Corg, δ15Norg), major, trace and rare earth element (REE) compositions and biomarkers (Fio et al., 2006, 2010).

Results and discussion

Rizvanuša and Brezimenjača sections in the Velebit Mt. area (1 in Fig. 1) consist of continuous marine carbonate rocks determined as Transitional Dolomite (TD) and Sandy Dolomite (SD). Lack of index fossils close to their contact and very clear lithological difference (Fig. 2) resulted in traditional opinion that the change in lithology corresponds to the PTB. Geochemical analyses have shown that $\delta^{13}C_{carb}$ values for the better exposed and in more detail analysed Rizvanuša section, were constant at the TD–SD lithologic boundary (~1–1.5 ‰), while the $\delta^{13}C_{org}$ revealed a decrease of up to 3 ‰. The $\delta^{15}N_{org}$ values of ~4 ‰ within the TD indicate a dominant influence of cyanobacteria, while lower values towards the TD–SD boundary indicate terrestrial material contribution. Input of terrigenous material and change from typical marine conditions was confirmed by the lowest whole-rock CaO and MgO contents, strong enrichments in most of the Major and REE, negative Ce anomaly at the TD–SD contact, and almost constant decrease of the $\delta^{18}O_{carb}$ throughout the section. Furthermore, Permian fossils have been found in the lowermost part of the overlying unit – Sandy Dolomites, and an abrupt negative excursion in $\delta^{13}C_{carb}$ was determined at both Rizvanuša and Brezimenjača sections within the Sandy Dolomites. This enabled the determination of the chemostratigraphic PTB in the Velebit Mt. area within the Sandy Dolomites unit, without recognizable facies change, 11 m above the lithological contact at Rizvanuša, and 0.2 m above at Brezimenjača section (Fio et al., 2010). Distribution of hopanes (biomarkers specific for bacteria) revealed no major change between the Upper Permian and Lower Triassic samples, but $\delta^{13}C$ of individual hydrocarbons indicated increase in primary productivity in Early Triassic (Fio et al., 2006).

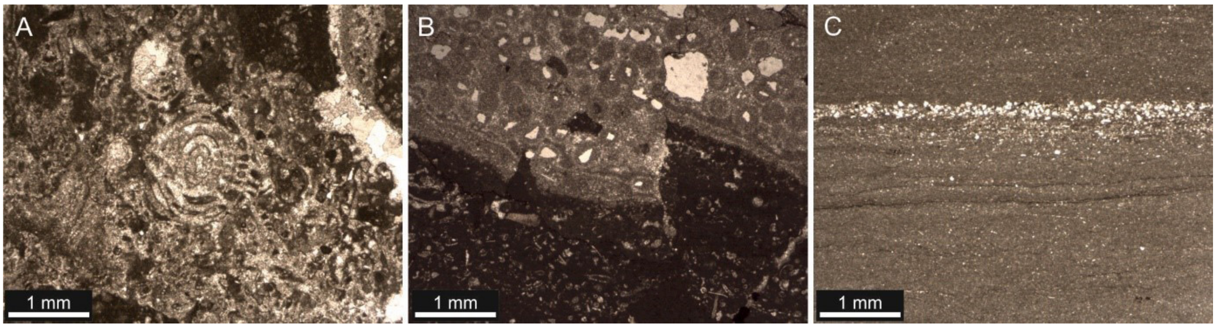

Fig. 2. Photomicrographs of the Transitional and Sandy Dolomite samples, Rizvanuša section (Velebit Mt. area). A) Shallow-marine dolobiopelmicrite with large fusulinid foraminifera within the TD, B) Erosional contact between dolomicrite of the TD and dolointrasparite of the SD, C) alternation of dolopelsparite and dolointrasparite in the SD unit.

Area between Bregana and Grdanjci villages in the northern part of the Samoborsko Gorje Hills in NW Croatia (2 in Fig. 1) contains tectonized deposits. Permian and Triassic deposits were therefore studied through six sections, to determine fossil assemblages and microfacies, and find a possible position of the PTB. Defined microfacies types indicated shallow-marine sheltered environments and shallowing-upward sequence during the Late Permian, occurrence of shallow-marine polymict breccia with rare tests of only small foraminifers in the middle part, and existence of environmentally tolerant microfossils in the upper part of the studied section, determined as Late Olenekian by the presence of foraminifera Meandrospira pusilla. Due to the stressful conditions and/or tectonic influence, transition from Permian to Triassic could only be indicated within the proposed "Transitional breccia" interval (Fio Firi et al., 2016).

Sedimentological features and fossil associations of the Lower Triassic deposits from the Muć-Ogorje area (southern Croatia; 3 in Fig. 1) enabled determination of seven facies associations, suggesting multiple changes concerning siliciclastic input and transgressive–regressive cycles from Dienerian to Spathian. Changes in sedimentology and associated biota throughout the succession revealed persistent environmental stress throughout the Early Triassic, as an aftermath of the PTB event (Fio Firi et al., 2022).

Conclusions

Presented research on the Upper Permian, Permian–Triassic Boundary and Lower Triassic deposits from several localities in Croatia (Velebit Mt., Samoborsko Gorje Hills, Muć–Ogorje area), confirmed several previous findings and, due to detailed sampling and geochemical analyses, provided new results on palaeontology, sedimentology and stratigraphy of these deposits. The chemostratigraphic Permian–Triassic boundary set in the Velebit Mt. area, found within succession of similar rocks and within single dolomite layers, represents the only area in Croatia where PTB is determined in detail. Partly exposed Upper Permian and Lower Triassic deposits of the Samoborsko Gorje Hills enabled palaeoenvironmental determinations, but between Permian and Triassic only "Transitional breccia" interval could be determined. Clastic and carbonate deposits from southern Croatia revealed Early Triassic environmental changes in the western Tethys epicontinental shelf area following the PTB.
Presented sections contribute to positioning of the Permian–Triassic boundary and determining the palaeoenvironmental and palaeogeographical reconstructions of this part of the Palaeo-Tethys during the Late Permian and Early Triassic, but also to understanding of the stressful conditions during the Late Permian and in the aftermath of the end Permian extinction.

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Quantifying the cause(s) of the end-permian mass extinction in shallow marine ecosystems

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The end-Permian mass extinction corresponds with numerous environmental changes, and the causes of extinction are often inferred from a seemingly synchronous timing of events. To improve our understanding of which environmental changes best explain the marine extinctions, we are collecting new, high-resolution geochemical, sedimentological and palaeontological data from around the world to statistically investigate the relationship between environmental changes and marine invertebrate extinctions. To investigate if this approach will work, a model study was undertaken using already published geochemical, sedimentological and palaeontological data from the most intensely studied Permian-Triassic section in the world, Meishan (China). The fossil database from this section includes 603 species, and the geochemical database includes 18 inorganic geochemical records. Firstly, we re-investigated the nature of the mass extinction in this section, and upgraded a pre-existing algorithm to handle large datasets, which quantifies the number of extinction pulses using the confidence intervals of taxa. Our investigation shows that at Meishan the mass extinction is best explained as an extinction interval that spans the Permian/Triassic boundary. In addition, the algorithm recognises that the nature of extinction varies between different fossil groups, most notably that ostracods have a unique timing of the mass extinction event. Subsequently, we used a regression model to explore the relationship with changes in diversity and the geochemical proxies, and then also investigated changes in faunal composition with the geochemical records using a partial distance-based redundancy analysis. Multiple proxies record a significant relationship with changes in diversity and composition, but $\delta^{18}O_{apatite,}$ a proxy for palaeotemperature dynamics, and $\delta^{114}Cd$, inferred to reflect primary productivity dynamics, show significant relationships with the extinctions. This suggests that not only do our results agree with recent earth system models looking at changes in aerobic habitat as best explaining the cause of the marine extinctions, but also nutrient availability was a significant factor, at least in the equatorial, marine extinctions.

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Ostracod body size and community evolution across the permian/triassic boundary at the Seis/Siusi section, Italy

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Body size can be a morphological characteristic that provides valuable insights into the biology, ecology, and evolutionary dynamics of organisms, both in the present and in the geological past. In the fossil record, a decrease in body size has been documented after mass extinction events and studied to better understand ecological selectivity. However, it is important to recognise that stratigraphic patterns and biases inherent in the fossil record can also influence the apparent pattern of body size selectivity. During the end-Permian mass extinction and recovery phase, a body-size reduction has been reported in different locations for several taxonomic groups, including gastropods, ostracods, foraminifera, brachiopods, ammonoids, and bivalves, with few exceptions. Ostracods, one of the most diverse and abundant metazoan groups during the Permian/Triassic boundary, provide an excellent opportunity to study the palaeoecological patterns associated with this event. In this study, we analysed the ostracod fossil record from the Seis/Siusi section in the Dolomites (Italy). The Seis/Siusi section consists of mixed carbonate-siliciclastic deposits accumulated in a shallow marine homoclinal ramp across the Permian/Triassic boundary. By analysing the ostracod record, we identified assemblages to quantitatively analyse community dynamics and measure the body size to investigate changes in body size at various taxonomic ranks. Our observations revealed a body size reduction of ostracod assemblages near the extinction horizon coinciding with a simultaneous faunal turnover. Furthermore, this body size change and faunal turnover correspond with a lithological change in the succession, where dolomitization influenced the preservation of fossils and, consequently, impacted the fossil record. Our evidence suggests that the body size reduction of ostracods at the Permian/Triassic boundary reflects the combination of ecological patterns such as the extinction of larger taxa, dwarfing of the survivors, and the diversification of smaller taxa.

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Update on permian conodonts in western and arctic Canada

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The most significant events of the Permian include the end of the late Paleozoic Ice Age (LPIA) and the end-Permian mass extinction (EPME) and yet the signature and timing of these events remain imprecisely understood, especially in western and arctic Canadian successions deposited on the north-eastern margin of the Panthalassic Ocean. The paleobiogeography, paleoecology, evolution, and extinction of conodonts can provide some useful insights. The Permian chert event (PCE) is associated with thermocline disruption and lysocline shoaling that led to the contraction of warm-water carbonate factories and expansion of silica factories. The PCE initiated in response to LPIA termination near the Asselian-Sakmarian boundary and continued until the EPME. During the LPIA conodonts are nearly cosmopolitan with biozones defined by Streptognathodus spp. on the shelf and by Mesogondolella spp. on the slope. During the early Sakmarian, Streptognathodus became extinct and was ecologically replaced by Sweetognathus. Species of Sweetognathus and descendant Neostreptognathodus were nearly cosmopolitan in distribution from the Sakmarian into the Kungurian. The last species of Neostreptognathodus in the Sverdrup Basin of the Canadian Arctic is N. pnevi that defines the base of the Kungurian. However, this genus ranges higher in lower latitudes continuing into the early Roadian in the Phosphoria and Delaware basins. The distribution of Permian conodonts becomes more provincial during the Middle and most of the Upper Permian. The last linkage to cosmopolitan distribution occurs during the early Roadian with the brief appearance of Jinogondolella nankingensis gracilis in the transgressive lower part of the Assistance Formation. This taxon is associated within a geographic cline with J. nankingensis nankingensis in the Delaware Basin of West Texas. Gene flow became restricted at this time leaving two distinct populations. Middle Permian conodonts in the north cool water province included relatively rare occurrences of longer ranging species of Mesogondolella (M. phosphoriensis and M. bitteri). In contrast, conodonts in the equatorial warm water province (EWWP), especially in the Delaware Basin and South China basins, included numerous shorter ranging species of Jinogondolella (J. aserrata, J. postserrata, J. shannoni, J. altudaensis, J. xuanhanensis, and J. granti). Distribution of species of Mesogondolella and Jinogondolella was likely restricted to a position below a thermocline whereas species of Sweetognathus continued to evolve above the thermocline in the EWWP. The abundant occurrence of gondolellids across most of the shelf areal extent and the restriction of Sweetognathus to proximal shelf margins suggests significant shallowing of the thermocline at this time. Tempestites delivered shallow-water taxa to mix with contemporaneous deeper water taxa providing a well-integrated high-resolution biozonation. The oceans became more acidic throughout the Late Permian and yet this did not affect conodont distribution. In the EWWP a new genus, Clarkina, evolved near the Guadalupian-Lopingian boundary in response to selection pressure associated with the major sea-level lowstand. Numerous species of Clarkina evolved rapidly in South China basins to provide a high-resolution biozonation within photozoan carbonate successions of the Wuchiapingian and Changhsingian, while Iranognathus, which evolved from Sweetognathus, continued into the early Changhsingian. In contrast, M. rosenkrantzi and M. sheni occur during the Late Permian in the Sverdrup Basin (Lindstrom Fm) and western Canada (Ranger Canyon and Fantasque fms); these formations were dominated almost exclusively by siliceous sponge assemblages leaving the impression that a major extinction event had already occurred. These sponges later became extinct near the end-Permian during a transgressive event when oceans warmed in association with Siberian trap greenhouse gas emissions. At this time, species of Clarkina migrated into the Sverdrup Basin and out-competed species of Mesogondolella. It has been suggested that this arctic extinction may predate the main EPME as recognized in South China where initial temperature spikes occur before the main hothouse. The PTB in the Sverdrup is associated with the occurrence of C. taylorae and Hindeodus parvus within the Otoceras boreale zone in the Blind Fiord Formation, Otto Fiord section. Conodonts were mostly unaffected through the EPME interval but underwent greater extinction at the end of the Griesbachian substage (early Induan) prior to an Olenekian adaptive radiation.

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Update on Permian conodonts in Oman : Rustaq, Wadi Wasit and Batain

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The Lower Permian of interior Oman includes glaciogenic diamictites (Al Khlata Fm), sandy limestone with cold-water brachiopods (Saiwan Fm), and channelized sandstone sheets of fluvial origin (Gharif Fm). None of these facies have yielded conodonts since conodonts are not typically found in cold water deposits and only rarely in the peri-Gondwana Cool Water Province. Middle Permian conodonts are rare in overlying shelf carbonates of the Khuff Formation. However, Middle Permian conodonts are abundant in locations associated with the base-Roadian opening of the Neotethys Sea including the Al Jil Formation at Wadi Wasit and in the condensed red ammonoid bearing limestone overlying basaltic pillow lava at Rustaq. Middle Permian conodont biostratigraphy involves short-duration zones related to populations of Jinogondolella within the Equatorial Warm-Water Province (EWWP) and longer-duration zones related to populations of Mesogondolella in cooler water provinces to the north and south. The succession of EWWP zones is nearly identical between South China and the Delaware Basin of West Texas, which were separated by the Panthalassic Ocean. The Neotethys was dominated by Mesogondolella, but sporadic occurrences of Jinogondolella may relate to a migration filter across the Cimmerian terrranes adjacent to the Paleotethys Ocean. At Rustaq the occurrence of late Roadian to Wordian M. siciliensis, J. aserrata, and Sweetognathus hanzhongensis overlies pillow lava. The base of the succession at Wadi Wasit includes M. saraciniensis and M. siciliensis indicating a latest Kungurian or early Roadian age. A latest Roadian to early Wordian fauna is indicated by J. nankingensis transitional to J. aserrata as well as M. omanensis. Toward the top of the section and below a sub-Triassic erosional unconformity J. shannoni indicates Capitanian age. In addition, M. omanensis (? transitional to Clarkina hongshuiensis) and J. altudaensis indicate a late Capitanian age. Locally a Wadi Wasit block includes Hindeodus parvus and the Permian-Triassic boundary. Upper Permian conodont biostratigraphy involves short-duration zones of Clarkina in the EWWP and longer duration zones of Mesogondolella in cool water. Clarkina has been postulated to have evolved during the GLB from either a Mesogondolella or Jinogondolella ancestor, but apparatus reconstruction would favour the latter. Clarkina populations vary morphologically across the Tethyan region with differences noted among South China, Iran and Oman. It is possible that some degree of hybribization is occurring within these competing populations. An Upper Permian Qarari unit is part of a WNW directed nappe in the Batain area of NE Oman. It is dominated by medium-bedded rhythmites (spiculitic and radiolarian hemipelagic dark lime mudstone) that accumulated outboard of a productive shelf, interspersed with rare echinoderm-bryozoan turbiditic grainstone and shelf edge-derived reef debris. The unit recorded deep-water sedimentation well below the photic zone, indicating that all recovered conodonts were pelagic during life. Two levels of white quartzitic sandstone in the Asselah area are associated with tectonic slices of the Qarari Limestone. Conodont biostratigraphy suggests that the lower sandstone unit may be associated with the Guadalupian-Lopingian Boundary (GLB) sea-level lowstand, but it remains uncertain whether the units are genetically related or superimposed by tectonics. A distinctive early Wuchiapingian conodont fauna occurs immediately above the lower sandstone at Asselah includes Clarkina cf. hongshuiensis, C. cf. dukouensis and a few specimens of Iranognathus movshovitchi and I. sosioensis ; the latter has been recovered from

the Wargal Limestone at the Chhidru Nala section in Salt Range of Pakistan. A mid-Wuchiapingian fauna, including C. cf. asymmetrica, C. cf. transcaucasica and C. cf. liangshanensis, occurs within the limestone above the upper sandstone. The uppermost sample of this limestone includes three specimens of late Changhsingian Clarkina cf. yini suggesting a major gap. This mixture may be associated with microkarsting as a major sequence boundary separates this unit from an overlying transgressive succession. This latest Permian transgressive succession includes C. cf. zhangi, C. cf. yini and one specimen of Mesogondolella sheni. This Upper Permian Qarari unit is in fault contact with the Upper Triassic Zal unit.

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Genetic memory of triassic conodonts

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This study investigates the importance of environment, paleoecology, and paleobiogeography in the evolution of organisms, specifically focusing on Triassic conodonts. The Triassic period experienced major mass extinctions, and the establishment of its stages was influenced by the biochronology of ammonoids in the 19th century. The Lower Triassic sub-stages (Griesbachian, Dienerian, Smithian, and Spathian) have been named by E.T. Tozer following his research in Canadian High-Arctic.

While 20th-century research relied on alternative biotic groups like conodonts and radiolarians for establishing the timing of open marine sequences, the 21st century has seen the dominance of isotopic excursion events. These events play a crucial role in the Early Triassic and can be categorized into five major events.Two of these events are negative (Permian-Triassic and middle-late Smithian transitions, while three are positive (Dienerian-Smithian plus Smithian-Spathian transitions and late Spathian-Early Aegean interval).These events are associated with environmental instability and sea-level changes, which are significant for understanding biological morphogenesis and evolution.

The Triassic period spans 51 million years and can be divided into the Induan–Olenekian, Anisian–Ladinian, and Carnian–Rhaetian intervals. The speciation rate varied throughout these intervals, with higher rates following the Permian extinction (13 S/Ma during the Induan–Olenekian) and decreasing over time (8 S/Ma during the Anisian–Ladinian and below 2 S/Ma during the Carnian–Rhaetian).

Triassic conodonts exhibit morphological adaptations in response to temperature and eustatic cycles. Speciation, radiation, and extinction events are non-random, and the processes of progenesis and neoteny (heterochrony) play significant roles in their evolution. Proteromorphosis and paedomorphosis are mechanisms that arise in response to sublethal environmental stress, often occurring after the radiation of fully developed forms during recovery stages following extinctions.

Keywords: Atavistic reversal, Darwinian anagenesis, Triassic conodonts, proteromorphosis, rediversification

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Guryul ravine and its treasures beyond the PTB

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The late Smithian and Smithian-Spathian bounday (SSB) marked by stepwise extinction events for conodonts, occurring approximately 2.7 million years after the main Permian-Triassic boundary extinction. This study, based on high-resolution sampling, examines conodonts and $\delta^{13}C_{carb}$ at the renowned Guryul Ravine section in the Vihi district, Kashmir. Between the Smithian cliff forming platy limestone and the Spathian massive limestone forming wall build up by amalgamated distal turbidites of thin bedded lime mud without marked bedding plane, two facies' changes occur. The first shows a sudden fine terrigenous arrival of dark greyish clay between thin bedded laminated lime mudstone and records the well-known positive $\delta^{13}C_{carb}$ excursion. The overlying 6 m thick, light beige, thin nodular muddy limestone beds is characterized by the highest positive $\delta^{13}C_{carb}$ values. This Smithian-Spathian transition revealed exceptionally abundant and relatively well-preserved conodont elements, enabling a detailed regional biozonation.

A high-resolution δ^{13}Ccarb curve was established for the entire Early Triassic interval, reliably concurring with previously documented carbon isotope excursions worldwide. By intercalibrating δ^{13}Ccarb data with conodont biostratigraphy, a refined global correlation of the Smithian-Spathian transition is obtained. Analysis of the nekto-pelagic conodonts reveals a sharp faunal turnover during the late Smithian, followed by a rapid radiation in the early Spathian.

The late Smithian extinction event coincides with a well-known positive δ^{13}Ccarb excursion recognized worldwide, although locally reaching an extraordinary amplitude of +12 ‰, which is interpreted as a diagenetic overprint. Our investigation of the Smithian-Spathian interval yielded over 1600 conodont specimens (P1-elements), representing 53 species belonging to 17 genera. Within these faunas, subdivisions for the early, middle, and late Smithian, as well as a reliable bracketing of the SSB about which the exact definition has still not been conclusively clarified to this date.

Among the identified species, we describe 17 new taxa, with 13 assigned to open nomenclature. The remaining four new species are Neospathodus aristatus n. sp., Neospathodus gulami n. sp., Icriospathodus reclinocrassatus n. sp., and 'Neogondolella' prima. Additionally, we classify Borinella buurensis and Scythogondolella milleri into five and two morphotypes, respectively. The conodont diversity observed during the Smithian and Spathian intervals at this study site represents the best documented in a Smithian-Spathian transition worldwide, encompassing both segminate and segminiplanate forms. This rich diversity enables the definition of 20 local biozones spanning the early Smithian to late Spathian interval.

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Morphological evolution of marine animals during the permian-triassic mass extinction

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The Permian-Triassic mass extinction (PTME), is the most severe biotic crisis in Earth's evolutionary history, with over 80% of marine species estimated to have gone extinct. The magnitude and duration of the biodiversity crisis during the PTEM have been thoroughly studied at both global and regional scales. Yet, the consequences of this mass extinction on the morphological disparity of marine animals and their evolution during this critical interval remains largely debated. Here we develop a new approach based on deep learning to extract morphological matrices (i.e., landmarks and semi-landmarks) from images of fossil specimens and use it to explore the evolution of disparity across the PTME. We apply our pipeline to a newly compiled high-resolution dataset of 730 species of six marine clades, spanning from the latest Permian to the earliest Triassic. We found that the mass extinction led to different disparity patterns across clades, with ammonoids and brachiopods showing a morphological reduction and selectivity, while extinctions in bivalves did not alter significantly their morphospace. We found that species with complex ornamentations and specialized shells were more vulnerable to extinction, while morphological generalist species were more resilient. Our approach offers new opportunities to study morphospace dynamics in deep time across large datasets. Our preliminary findings, show that the magnitude and selectivity of mass extinctions had nuanced impacts on morphological disparity among clades.

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Reconstructing local marine redox conditions of tethys area during the end permian mass extinction using I/Ca

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The end-Permian mass extinction, occurring approximately 252 million years ago, stands as a pivotal event in the Phanerozoic era, resulting in a substantial loss of biodiversity on Earth. This catastrophic phenomenon witnessed 70 to 95 percent of terrestrial and marine species extinction. Extensive research spanning decades has aimed to uncover the primary trigger of this extinction event, with the expansion of anoxia emerging as a leading hypothesis for extinction in the marine realm. However, the spatiotemporal constraints of expanded reducing conditions in marine environments remain subjects of the ongoing investigation surrounding the end-Permian mass extinction. In a recent study conducted by Newby et al. (2021), compelling evidence (i.e., thallium isotopes) emerges of a brief period of global oxygenation occurring just prior to the main phase of the extinction event, a phenomenon not yet revealed by any other marine redox proxies. Among the suite of proxies developed for the reconstruction of ancient environmental conditions, the ratio of iodine-to-calcium (I/Ca) has recently gained prominence as a local to the regional indicator of oxygen contents of carbonate-dominated marine environments. Iodine is a redox-sensitive element, among the earliest elements to be reduced under low-oxygen conditions in marine settings. This study aims to apply the I/Ca proxy to carbonate-dominated Permo-Triassic successions within the Tethys Ocean region, which hosts continuous successions through this critical time interval. Some Permian-Triassic localities in Iran, Armenia, and China were selected due to their well-documented and nearly continuous successions that are ideal for testing this hypothesis of a brief marine oxygenation, but in shallow shelf environments. Through detailed integration of our new I/Ca records with existing paleontological and sedimentological datasets from these successions, our research aims to provide a comprehensive and nuanced spatiotemporal understanding of marine oxygen levels and the rates of end-Permian mass extinctions. Detailed and integrative studies such as ours have the potential to uncover crucial data that will enhance our comprehension of how marine redox evolution contributed to the end-Permian mass extinction at the local to regional scale. By deciphering the dynamics of oxygen levels on carbonate platforms during this period, we may also gain valuable insights into the interplay between environmental changes, climate, oceanographic conditions, and ecosystem collapse over deep time.

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The permo-triassic formations of the Hellenides developed at the base of carbonate platforms or oceanic basins

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The Hellenides comprise Mesozoic shallow-water carbonate platforms developed above crustal fragments/terranes of Pre-Alpine continental crust (H1, H3, H5, H7) and oceanic basins (H2, H4, H6, H8) developed in between the drifted northwards carbonate platforms from Gondwana to Europe. The rifting phase of the continental terranes took place in the passive margin of Gondwana during Late Paleozoic - Late Triassic, comprising volcano-sedimentary sequences/complexes, with volcanic formations, clastic sediments, pelagic limestones and other more particular formations such as evaporites, conglomerates and olistholites from the marginal zones of the rifted basins. Immediately after the breakaway of the large continental fragments and their new isostatic equilibrium in the Tethyan realm the shallow-water carbonate platforms are established above the previous rifting complexes. Throughout the northward drifting of the terranes the carbonate sedimentation acquired thick successions of 1-2km thickness. The docking to the active European margin occurred during the establishment of flysch sedimentation on top of the carbonate platforms within the fore-arc basins of the Hellenic Orogenic belt from Jurassic to Early Tertiary. The age of the volcano-sedimentary Permo-Triassic formations differs in each terrane with older ages of Late Carboniferous – Permian observed in the northern terranes (H7, H5,)and younger ages of Permian to Scythian – Anisian (H3) and Permian to Karnian (H1) in the southern ones. Thus, Permian carbonates form the base of the platforms in the H7 (Pangeon) and H5 (Lesvos autochthon) terranes whereas Middle Triassic carbonates occur at the base of terrane H3 (Parnassos, SubPelagonian) and Late Triassic (Karnian) at the base of terrane H1 (Tripolis, Ionian). The same age differences are observed at the base of the pelagic/oceanic sequences of the intermediate oceanic basins (Karnian for the Pindos basin, H2, Scythian for Maliac/Vardar basin, H4). Some special cases of particular formations are observed: (i) in the case of the External Carbonate Platform H1 with Gypsum and related evaporites of Permian-Triassic age in the Tripolis, Ionian and Western Crete units. Additionally, a passive continental margin with Upper Paleozoic neritic limestones occurs beneath the relative autochthon unit of Mani in central Crete (Fodele). (ii) in the case of the Internal Carbonate Platform H3 with a distinctive formation of Permian-Lower Triassic clastics including olistholites/blocks of Permian neritic limestones with characteristic outcrops in Salamis Island, Attica and Evia. Another Permian-Lower Triassic formation with olistholites of Ordovician – Carboniferous formations is observed in the Chios autochthon, including both neritic and pelagic Paleozoic facies. (iii) Some cases of Permian shallow-water carbonate platforms are observed within the Subpelagonian and Pelagonian units of the Internal Carbonate Platform H3 in the outcrops of Hydra Island, where the platform if followed by Triassic volcanics and limestones and in the Chios Allochthon unit (H5), where the Permian platform was disconformably covered by the Upper Liassic carbonate platform with the whole Triassic missing.

Interpreting the end-permian uranium isotope excursion

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Ocean anoxia has long been hypothesized as a kill mechanism for the end-Permian mass extinction, the most severe biodiversity crisis of the Phanerozoic. Initially, support for this scenario came from proxies for local redox conditions, such as bioturbation levels, extent of black shales, sizes of pyrite framboids, and cerium anomaly values. Recently, advances in mass spectrometry coupled with recognition that uranium isotopes are fractionated in seawater and sediments during reduction of soluble U(VI) to insoluble U(IV) led to the development of uranium isotopes in sedimentary rocks as a paleoredox proxy. Because uranium should be well mixed in seawater, U(VI) incorporated into carbonate strata deposited under locally oxygenated conditions should function as a passive tracer of the $\delta^{238}U$ of seawater and, thereby, as a global paleoredox proxy. However, imprecise knowledge of some key parameters in the uranium cycle combined with noise in empirical records makes interpretation of uranium isotope data a challenge, both for producing best estimates of the extent of anoxia across time as well as estimating associated uncertainty. Here, we present an approach to quantifying the extent of anoxia and associated uncertainty using Monte Carlo simulations of the uranium cycle followed by model-data comparison using the Approximate Bayes Calculation (ABC). Following this approach, we estimate an increase in the extent of seafloor anoxia across the Permian/Triassic transition, reaching 18% of the seafloor (95% CI: [11%, 47%]), lasting anywhere from 20 kyr to 1.2 Myr. There is an inverse relationship between the extent and duration of anoxia in the set of best-fitting models. This initial pulse of pronounced anoxia is followed by a prolonged aftermath, which continues through the remainder of the study interval, of less extensive, yet still expanded, anoxia covering 7.8% of the seafloor (95% CI: [1.6%, 48.9%]). Both expanded and protracted anoxia are required to fit existing data, with no indication of full re-oxygenation during the study interval. An advantage of the Monte Carlo – ABC approach is that estimates can be updated as new data become available simply by repeating the ABC on the existing set of Monte Carlo runs, better illuminating the value of additional information and enabling more strategic collection of future data.

A new lower triassic fossil record in the western United States : tiny fossils hiding in plain sight

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The Lower Triassic is characterized by long-term environmental stressors, like low oxygen settings and exceedingly warm temperatures. While the biological consequences of Early Triassic environments have been examined in detail, the taphonomic implications of these settings have received less attention. Our work demonstrates a prevalence of small shelly-style fossil preservation in upper Lower Triassic carbonates of the Virgin Limestone in the western United States. In insoluble residues of carbonates across localities that span the nearshore to the middle shelf, fossils are replaced by apatite with minor glauconite and iron oxides. These minute fossils consist mostly of organisms also known from their macrofossil record, such as gastropods, bivalves, and echinoderms ; however, novel occurrences, such as a new species of ophiuroid and previously unknown foraminifera have been identified. The presence of minerals such as apatite and glauconite in these samples is indicative of pore waters experiencing oscillating redox conditions, where the original skeletons are molded and occasionally replaced during early diagenesis. The size of the fossils plays an important role in this mode of fossilization ; fossils > 300 microns are rarely preserved by these minerals. Our work reveals a hidden taphonomic pathway in Lower Triassic rocks, illustrating that the environmental stressors that led to long-term delayed recovery also aided in this mode of fossilization, allowing for the discovery of an unknown taphonomy and diversity among the smallest fossils. Future work examining Lower Triassic carbonates across the globe would enable an expansion of this important record.

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Steady states and bifurcation diagram for the permian-triassic climate

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General circulation models have been used to simulate climates of the past on the global scale, and to be compared to geological data collected in various localities in the world, representative of local or regional conditions. Initial and boundary conditions are set according to the geological reconstructions of paleogeography, surface temperature, atmospheric CO_2 content, solar energy input, etc. Then, the numerical model is run for several thousand years until it equilibrates, and the resulting climate is analysed. However, our knowledge of deep-time climates is subject to large uncertainties and in general a wide range of initial and boundary conditions needs to be explored.

A steady state is reached when a balance between energy received from the Sun, dissipation and feedbacks occurs. Because of the presence of several feedbacks, there are several ways for these mechanisms to equilibrate, and thus in general there is no unique resulting climate under the same forcing. Such situation, where there are different possible steady states and the final state only depends on the initial conditions, is referred to as ‘multistability’. A transition between two steady states remains possible under a variation of the forcing (either smooth or brutal, e.g., solar energy input, pCO2 content, asteroid impact).

Here, we apply the multistability framework to simulate climates corresponding to the Permian-Triassic paleogeography. Simulations are performed with the MIT general circulation model in a coupled configuration including atmosphere, ocean, sea ice and land, and the paleogeographic reconstruction is provided by PANALESIS. First, we use a constant forcing (i.e., fixed incoming solar energy and pCO2 content). We explore a variety of initial conditions and let the numerical model evolve until a steady state is reached. This procedure allows us to identify the steady states. Then, we vary the pCO2 content to construct the bifurcation diagram, which allows us to identify the stability range of each steady state and the position of tipping points. The required change in forcing to shift from one state to another helps to understand the oscillations in the climatic conditions observed during the Early Triassic. We finally couple offline the climate model with the vegetation model BIOME4. The two are run alternatively until convergence, and the obtained vegetation distribution can help discriminate which one of the steady states likely existed at the Permian-Triassic Boundary and its Early Triassic aftermaths.

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Microbialites and sponges : unusual facies after the end-permian mass-extinction around the Neotethys

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The end-Permian mass extinction greatly affected the sedimentary record, with the prolific upper Paleozoic skeletal carbonate factory replaced abruptly by a non-skeletal carbonate factory. During the earliest Triassic, microbialites and other microbial-influenced sedimentary structures flourished. Aymon Baud was a pioneer in the research on these peculiar sedimentary structures and published several seminal articles on this subject. I will here review the different microbial structures occurring around the Neotethys in Armenia, Turkey, Iran, Oman, Italy, and Hungary. The western margin of the Neotethys (Northern Italy) is dominated by extensive oolitic deposition, while the southern margin record oolitic levels followed mainly by thrombolite and some accessory stromatolites (Turkey, Zagros, Emirates). On the northern margin of the Neotethys, or following the reconstructions on the southern margin of the Paleotethys, the Cimmerian plates show a differentiated image with oolites followed by thrombolites and accessory stromatolites on the Central Iran and Alborz plates, whereas the ooids are completely absent from Sanandaj-Sirjan and Lesser Caucasus plates. There, dendrolites and thrombolites dominate with accessory stromatolites and some oncoidal levels. In deeper environments, the microbialites, if present, are generally dominated by stromatolites (Slovenia, Hungary). Over the years, an accumulation of sedimentological, palaeontological, and geochemical data has revealed a more complex image of these microbial-induced depositions with alkalinity, nutrient gradients, and wave energy as the main controlling factors of their forms, size, and repartition.

The recent discovery of the importance of non-spicular demosponges and sometime microconchids in the framework of these microbial structures highlights rather a metazoan-microbial association than purely microbial to build these bioherms. The non-spicular demosponges are, as non-biomineralized fossils, difficult to recognize and prone to debate. However, the careful application of identification criteria allows their identification in several thrombolites around the Neotethys. Their presence probably gives structure and stability to the growing microbialites and favored their growth in bioherm rather than in biostrome and thus an early recovery, even depauperate, of the reef ecological environment.

Geohazards specialized geopark of Armenia, the Chanakhchi geosite with unique permian-triassic succession

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The geology of Armenia is characterized by a diverse array of rock formations that record a long and complex history of geological events. Proposed Armenian geohazard-related Geopark will consist of twenty-six geosites, each of which represents evidence of different geological hazards. Geosites are concentrated in a relatively limited area of about 4.573 km^2, which represents about 15.3% of the total area of the Republic of Armenia (Avagyan et al., 2021). The area is prone to a range of geohazards, including earthquakes, landslides, and volcanic eruptions, which have shaped the landscape over millions of years. Here sedimentary sequences have preserved evidence of several mass extinction events that occurred at different points in the Erath's history in the Late Devonian (375-360 Ma), in the Permian-Triassic (~252 Ma), in the Paleocene-Eocene (thermal maximum, 56 Ma), in the Eocene-Oligocene boundary (abrupt cooling 33.9 Ma).

The Zangakatoun (Chanakhchi) section as a hazard-related geosite is also proposed for Armenian Geopark, which provides evidence of past geological hazard and environmental changes in the aftermath of the end-Permian mass extinction. This section is unique in terms of the development of the basal Triassic giant Sponge-microbial (SMB) build-ups up to 15m of vertical extension with asymmetrical sides due to steady bottom current. The overturned cone-shaped buildup geometry has a top head diameter up to 8m width that consists of numerous thrombolite domes. Changes in palaeoenvironments during the basal Dienerian kummeli conodont zone suddenly break-off the thrombolite's growth. The overall duration of these post-extinction SMB is estimated at 700'000 years (Baud et al., 2017).

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Mass extinction survival guide – plant fossils from the Arctic

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For marine animal life the Permian-Triassic mass extinction was devastating, the recovery patterns in its the aftermaths were quite complex and are still controversially discussed. Plants entered the stage of the Permian–Triassic mass extinction discussion rather late. But the discussion on how plants dealt with fundamental environmental changes associated with the extinction event is in no case less controversial. Have they been victims or heroic survivors? Here I present findings from Arctic palynology research that shed light on the dynamics of plant ecosystems and possible prerequisites for surviving a mass extinction.

The Arctic has long been in the focus of palynological research. Initially, the exploration of Permian coal deposits was of interest, later the solution of stratigraphic questions and in the last decades also to answer questions concerning the Permian-Triassic mass extinction.

The Permian phytogeography included four main plant kingdoms. The Canadian Arctic, Greenland, the northern part of Norway, the Barents Sea, and the Russian Platform are combined in the Subangaran province. What is common to the palynological assemblages of these Subangarian regions is that those of the upper Permian and lowest Triassic are quite similar. A decline in diversity across the Permian–Triassic boundary was not observed. Basically, all lineages survived into the basal Triassic, but plant ecosystems remained not unscathed.

In some places (Greenland and Norway) significant short-term changes in the abundances structure of plant groups were documented. During the negative carbon isotope excursion that marks the extinction event globally, spore producing plants were dominant for a geologically short time interval. This event was also recorded on the Norwegian shelf and exemplifies that the plant ecosystems reacted to the environmental changes. There, abnormal morphologies of spores and pollen grains were also interpreted as consequence of the environmental changes.

Plants are primary producers and have therefore fundamentally different requirements for life compared to aquatic and terrestrial animals. The wide geographic distribution of plant lineages in the Arctic could have buffered environmental changes to some extent, providing enough refuge areas, whereas on the local scale changes in vegetation composition are evident and show the capability of plants to adapt to environmental changes from ecosystem level to plant level.

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The palynological response to the middle and late permian extinction events across the equatorial and tropical belts

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Recently, the end-Guadalupian (middle Permian) biotic crisis has been proposed as the sixth mass extinction event, ranking third in taxonomic severity after the end-Permian and end-Ordovician (Hirnantian) extinctions (Rampino and Shen, 2019). Drivers as ocean anoxia and acidification associated with flood basalt volcanism from large igneous provinces were invoked. The massive release of greenhouse gases such as CO_2, SO_2, and CH_4, triggered by volcanic activity, led to extremely high global temperatures, profoundly impacting marine and terrestrial taxa.

In this study, we examine changes in microflora throughout the middle to late Permian period in the northern Gondwana margin : specifically in the Zagros Basin (SW Iran) and in the Zal and Ajabshir area (NW Iran). These well-preserved and chronologically calibrated Iranian successions serve as crucial reference sections for studying this geological time interval. Our aim is to understand the response of paleovegetation communities to the end-Guadalupian biotic crisis.

The Guadalupian microfloral assemblages from the studied areas displays a similar morphological composition to those documented from coeval Northern Gondwana regions, including Oman, Saudi Arabia, Southern Turkey, Iraq, Pakistan, and others (e.g., Stephenson et al., 2003 ; Stephenson, 2008 ; 2018 ; Stolle, 2007 ; Stolle et al., 2011). The Roadian-Wordian microflora points to a xeromorphic and xeromorphic-hygromorphic ecoclimatic affinity. The younger Wordian-Capitanian microflora is characterized by the persistence of previous palynoelements in assemblage with other specimens here firstly occurring. Aberrant sporomorphs also appear, serving as early indicators of the end-Guadalupian ecosystem crisis. The Wordian-Capitanian palynoelements indicate a predominance of hygromorphic ecoclimatic affinity and a minor presence of xeromorphic and xeromorphic-hygromorphic forms throughout the assemblage. After the end Guadalupian crisis, no floristic turnover was recorded in the early Lopingian (Wuchiapingian) palynoflora : the microflora consists of the same sporomorphs recorded in the Guadaluapian assemblages. It is predominantly characterized by a xeromorphic-hygromorphic flora. Going upward in the end of Permian, the microflora is also marked by a proliferation of Lycopodiaceae spore suggesting humid conditions. Nevertheless, the morphological composition of the Lopingian microflora points to a period of biodiversity stabilization or continued biodiversification after the end-Guadalupian crisis. Based on our microfloristic analysis of continuous marine Guadalupian to Lopingian successions, at least in this region of Northern Gondwana, land plants could be considered as the survivors of the extinction events. Currently, there is no compelling evidence of a mass extinction among land plants at the end of the Guadalupian. Although further palynological studies from coeval marine successions in other areas are necessary, it appears evident that the “ sixth mass extinction ” documented in the animal fossil record did not correspond to a mass extinction event in plants. The only signal of this crisis is supported by the presence of aberrant sporomorphs, which may have resulted from mutations induced by high levels of ultraviolet radiation during that time interval (Liu et al., 2023).

Reference list and corresponding author: Amalia Spina

Oxygen isotope compositions and temperatures of early triassic seawater: A clumped isotope perspective

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Recent studies have demonstrated that precise clumped isotope measurements of well preserved carbonates allows primary and diagenetic processes to be readily distinguished [1], both of which can influence the isotopic compositions of carbonates. In contrast to measurements of $d^{18}O$ only, clumped isotope compositions (D_{47}) may provide absolute temperatures of crystallisation independent of the isotopic composition of the water that the carbonates crystallized from. This study summarizes the results of clumped isotope analyses of calcite from Early Triassic carbonate sequences. Samples include abiotic micritic limestones intercalated within highly fossiliferous, nectic and benthic fauna of the middle Dienerian (Wadi Ad Daffa and Ras Al Jin, Batain basin, Oman), individual fossil rhynchonelliform brachiopods and bulk carbonate rocks of the late Smithian and early Spathian (Hawasina nappes and Batain melange, Oman), all originally deposited in the Neotethys on offshore seamounts [2].

Absolute D47-temperature estimates from three different Dienerian micrites in two sections reproduce well for RAJ at 29 ±2.0 °C (n=3), but give clearly diagenetic temperatures for WAD2-MC with 47 ±3.5 °C (n=59 and WAD2-MP with 50 ±13 °C (n=4); all calibrated against ETH-1, -2 and -3 standards [3]. The $\delta^{13}C$ (VPDB) and $d^{18}O$ (VSMOW) values are also homogeneous (RAJ: $\delta^{13}C$ of +2.4 ±0.1 ‰, $\delta^{18}O$ of 30.5 ±0.2 ‰; WAD2-MC: $\delta^{13}C$ of +2.0 ±0.4 ‰, $\delta^{18}O$ of 28.9 ±0.3 ‰; WAD2-MP: $\delta^{13}C$ of +1.4 ±0.3 ‰, $\delta^{18}O$ of 27.7 ±0.1 ‰) and higher clumped isotope temperatures correlate well with lower $\delta^{18}O$ values of the same carbonates. Clumped isotope thermometry supports Dienerian Neothethys subequatorial seawater temperatures within the range for the modern sea surface (25 to 32 °C) and hence gives calculated seawater $\delta^{18}O$ for the RAJ section of between -0.4 to +2.3 ‰, also similar to the range of modern, evaporated sea-surface waters in subtropical oceans. The large range and higher average temperatures for the WAD sections but with lower $\delta^{18}O$ values are likely due to diagenetic alteration in a rock-buffered system in the presence of seawater.

For the Smithian to lower Spathian absolute temperatures can be estimated from individual fossil rhynchonelliform brachiopods as well as bulk carbonates. Results suggest that sampling along individual brachiopod growth lines represents the best strategy to obtain clumped isotope temperatures. Best estimates support Early Triassic seawater temperatures in the equatorial realm within the range of modern equatorial sea surface temperatures of 27 to 32 °C. Furthermore, calculated water $\delta^{18}O$ values for samples collected along growth lines are between -0.9 and +1.4 ‰, also similar to the range of $\delta^{18}O$ values of modern seawater. Bulk rock carbonates, however, give higher clumped isotope temperatures of between 41 to 90 °C; as well as higher calculated water $\delta^{18}O$ values at those temperatures. In general, higher clumped isotope temperatures correspond to high $\delta^{18}O$ values calculated for water in both bulk rock and brachiopods, also indicative of diagenesis in a rock-buffered system in the presence of seawater or exchanged seawater. The results suggest that the oxygen isotope composition of Early Triassic seawater during the late Smithian to early Spathian was about –1 ‰. Using this brachiopod-based $\delta^{18}O$seawater value, the stable O-isotope analyses of oxygen in conodont phosphate (δ^{18}OPO4) from the same sequences provide temperatures of between 32 to 39 ºC for the late Smithian, but cooler temperatures of between 25 to 27 ºC for the Early Spathian.

These combined results for the Dienerian up to the Spathian are congruent with recent indications that seawater δ^{18}O values remained relatively constant at about 0 ±2 ‰ throughout the Phanerozoic.

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Tracking back Permian – Triassic sections from Oman over the Permian to Cenozoic : Geodynamic and palæogeographic implications

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Abstract : We use herein the Panalesis model to understand the geodynamic and palæogeographic evolution of many stratigraphic series that we have studied in Oman. Panalesis proposes that the Permian extensive phase is associated with the Panjal Traps formation and the detachment of the Cimmerian Blocks. The analogy with the current Traps of Etendeka and Walvis Ridge made it possible to refine the positions and the palæogeography during the emplacement of these series. The formation and rotation of the Indian plate causes an arc to form north of the North Omani margin. According to Panalesis, the arc is 3880 km away from the margin, implying the formation of a ‘ classic ’ subduction zone which brought the arc back towards the margin. The actual obduction only occurs in a second step, by ridge failure of a spreading center which jumped just behind the arc. On the East Omani margin, Panalesis suggests that the transform fault between the Africa and India plates underwent compression in connection with the collision of the Indian Promontory with Eurasia. A shortening of up to 250 km then produces the metamorphism of the Batain Nappes. Finally, we propose the presence of an oceanic plateau – the Owen Plateau – to explain that the subduction, then along the continental margin of the Arabian plate, jumped towards the current Owen Fracture Zone.

Keywords : Geodynamics, palæogeography, Oman.

1 – Introduction

In Oman, we have re-examined in detail several sections that span the Permian–Triassic Boundary (PTB) and the Lower Triassic (Edward *et al*., 2022, 2023). Although much studied (see Baud, 2023 and references therein), the palæogeography of these sections and more broadly the geodynamic history of the northern and eastern Omani margins remain debated.

Based on the Panalesis model of plate tectonics (Vérard, 2019.b), we propose here to 1) place the various sections in their palæogeographic context in the Triassic, 2) trace the palæopositions of the sections from 300 Ma to present-day, and 3) specify a credible geodynamic scenario associated with this evolution.

2 – Stratigraphy Of The Permo-Triassic Sections

The detailed study of the PTB and the Lower Triassic (Smithian – Spathian Boundary ; Edward *et al*., 2022, 2023) concerns in particular the sections of Wadi Musjah, Jebel Rabat A (Northern Omani margin) and Jebel Aweri (East Omani margin), but here we will also consider other sections (Fig.01).

Successions have been well-described in the literature (*e.g.* Pillevuit *et al.*, 1997; Chauvet, 2008; Scharf *et al.*, 2021 and references therein) and synthesized in Baud (2023). These descriptions made it possible to properly constrain their depositional environments and their positions in relation to the Omani passive margin (Fig.02). They will therefore not be recalled again here, and we will focus instead on the geodynamic evolution of the region.

3 – Geodynamic Evolution

3.1 – Extensive phase: Rifting and oceanization

Between 300 Ma and 290 Ma, the first traces of extension (metatuffites of 298 ± 3 Ma after Gray *et al.*, 2005); see also Pillevuit, 1993; Angiolini *et al.*, 2003) probably indicate the very beginning of the rifting phase between Gondwana and the Cimmerian Blocks (or Cimmeria; Şengör *et al.*, 1985; Stampfli, 2000; Stampfli & Borel, 2002; Stampfli *et al.*, 2002). This extension is consecutive to the formation of Pangæa (Stampfli *et al.*, 2013) which saw the collision between Gondwana and Laurussia in the East being extended to the West by the subduction of PalæoTethys. However, the traction of the plate had no notable effect in the oceanic lithosphere due to its rheological profile (Cloos, 1993; Fig.03). On the contrary, as soon as the continental crust becomes thick enough (Cloos, 1993; Fig.03), a rifting zone could have occurred along the North Gondwana passive margin. The rifting was also accompanied by the arrival of a mantle plume which will give rise to the Panjal traps (Chauvet *et al.*, 2008). The area between northern India and Oman is then marked by a triple junction connecting a "Madagascar branch" and a "NeoTethys branch", reminiscent in many aspects of the current Afar area. The "Madagascar branch" of the rifting will be abandoned, while the "NeoTethys branch" will develop until oceanization (in the sense of the separation of two continental crusts, possibly around 268 ± 5 Ma according to the Panalesis model). It thus corresponds to the break-up of the Cimmerians Blocks from Gondwana and the formation of two conjugate passive margins around the NeoTethys Ocean. Throughout this phase, the Panjal hotspot remained active and created a plateau that extended over the passive margin and the continent – ocean boundary (COB), and continueed into a chain of seamounts. The tail of the mantle plume was probably "captured" by the mid-ocean ridge and the seamounts (*e.g.* Jebel Kawr, Jebel Misfah), still active in the Ladinian – Lower Carnian, underwent significant thermal subsidence associated with the distance from the ridge. The evolution of the Etendeka traps (Namibia) towards the Walvis Ridge and the Tristan da Cunha hotspot can, in some respects, be considered as a current equivalent of this system (Fig.02.d).

According to the geochemistry of basalts (Lapierre *et al.*, 2004), the sections of Budday'ah, Rustaq and the top of the section of Al Ajal are seamounts linked to oceanization (with OIB and/or MORB signature; their "group 1"); the sections of Ba'id, Wadi Musjah, Jebel Rabat, and the base of Al Ajal have OIB (plateau) signatures with no continental crust contamination (their "group 2"); and the sections of Wadi Aday, Wadi Al Hulw have OIB signatures with continental crust contamination (their "group 3"). In the Carnian (Fig.02.a-c), the sections considered can then be positioned in their palæogeographic configuration. The Omani margin is stable and calm until the end of the Jurassic.

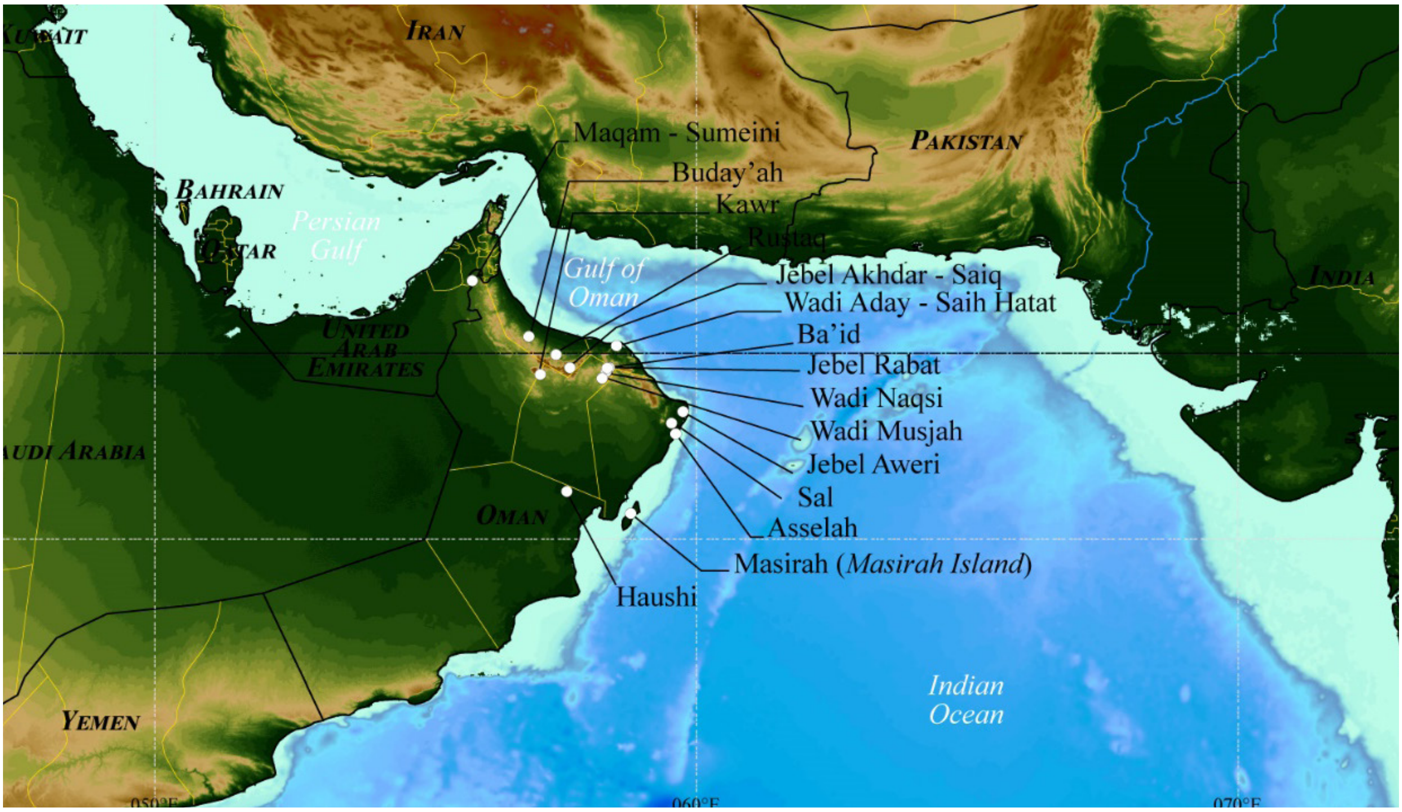

Fig. 01. Localisation of the stratigraphic series considered herein.

4 – Geodynamic change : Rotation of the Indian plate relative to the African plate

From the Callovian (König & Jokat, 2010 ; Mueller & Jokat, 2019), a new rifting zone is created between East and West Gondwana, and runs from the Weddell Sea, along the Mozambique Channel and the Somali Basin to the Eastern Omani margin. We can associate this rifting with the change in the stress regime caused by the subduction of the mid-oceanic ridge of the NeoTethys under Asia (Fig.04). Indeed, the traction exerted by the slab-pull is no longer accommodated by the mid-oceanic ridge, but is transmitted directly to the Gondwana plate, which is already subjected to a divergent traction by slab roll-back effect to the south.

At sea, the point of rotation between the two East and West Gondwana plates (Fig.04) is located on the old transform fault along which the Omani seamount chain was set up. This old transform fault is subject to extension to the south of the point of rotation and compression to the north, which leads to the rupture of the mid-oceanic ridge (ridge failure) and its transformation into an intra-oceanic subduction zone.

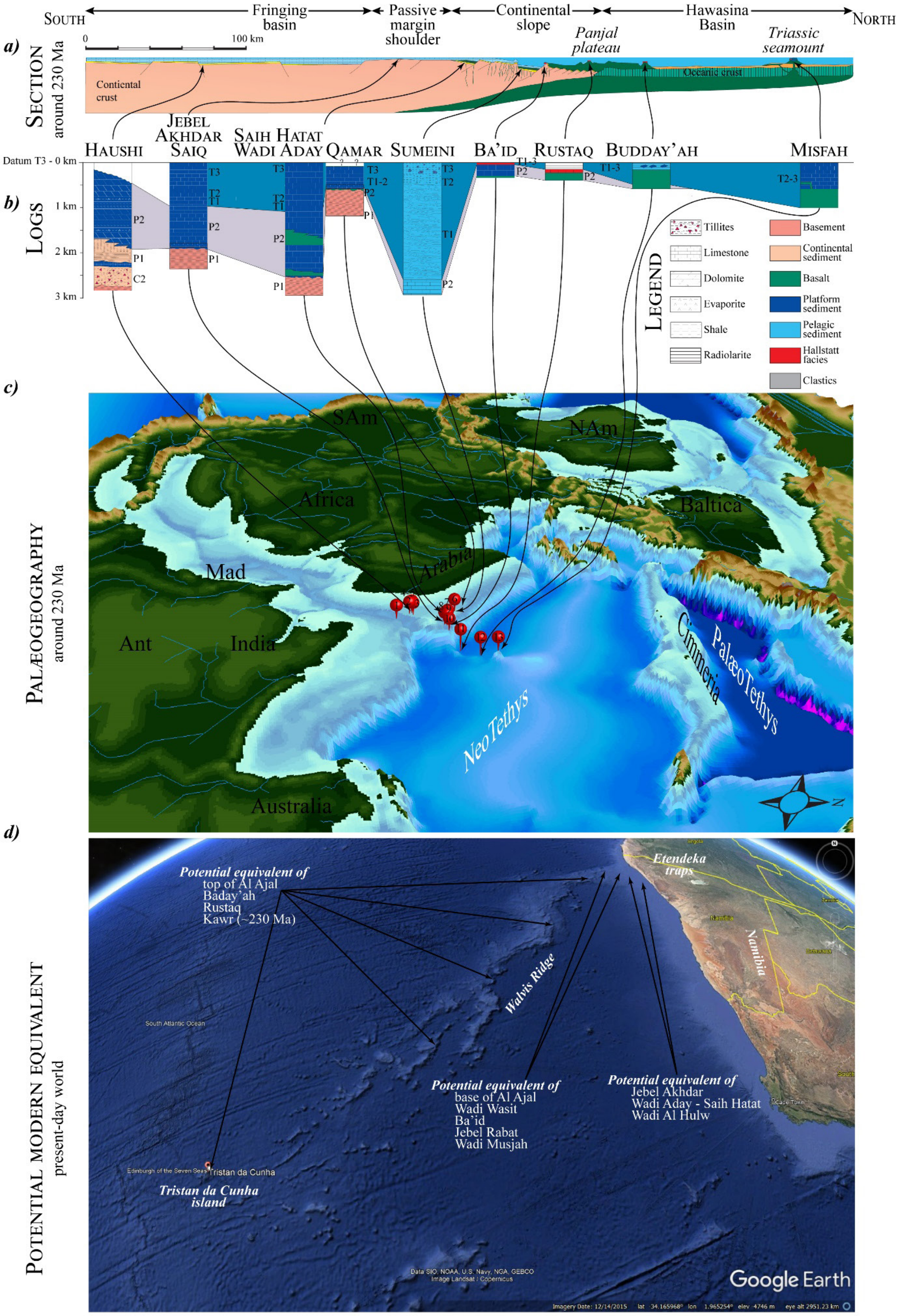

Fig. 02. a) Palinspastic reconstruction of the north-omani margin around 230 Ma; b) Synthetic logs and correlation of the sections; c) Palæogeographic reconstruction after the PANALESIS (v.0) model; 1. Masirah – Mursays; 2. Asselah block; 3. Jebel Aweri; 4. Sal; 5. Haushi; 6. Maqam – Sumeini; 7. Jebel Akhdar – Saiq plateau; 8. Wadi Aday – Saih Hatat; 9. Ba'id; 10.1. Jebel Rabat; 10.2. Wadi Musjah; 10.3. Wadi Wasit (block); 11. Rustaq; 12. Buday'ah; 13. Misfah; d) Potential equivalent of the Omani system in the present-day world.

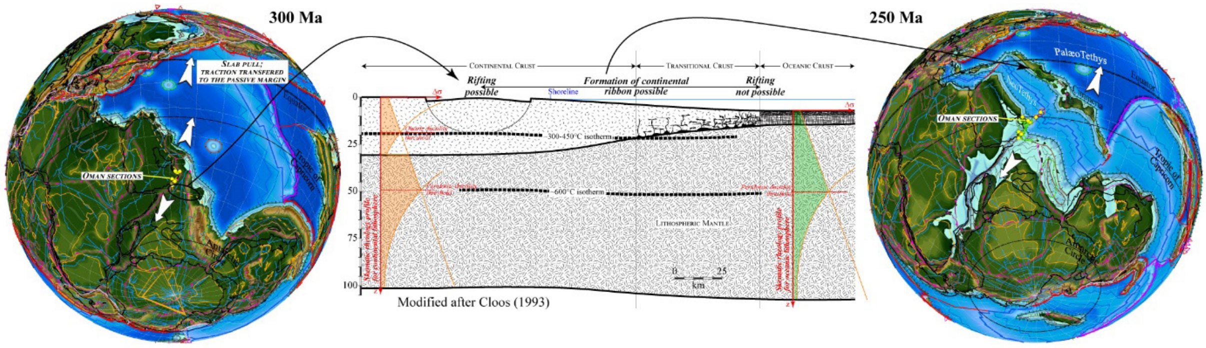

Fig. 03. Palæogeographic reconstruction around 300 Ma and 250 Ma (Panalesis.v.0), explanatory sketch of the detachment of the Cimmerian Blocks from the Gondwana margin (adapted from Cloos, 1993, *op.cit.fig*.13).

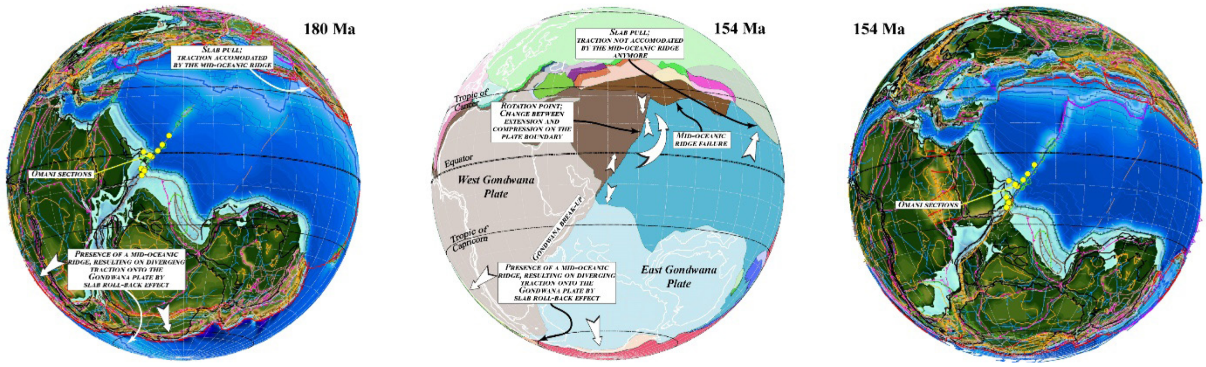

Fig. 04. Palæogeographic reconstructions around 180 Ma and 154 Ma [*i.e.* magnetic anomaly M25], and the corresponding tectonic plates (random colours) at 154 Ma (Panalesis.v.0), highlighting the change in geodynamics (subduction of the mid-oceanic ridge under Asia) linked to the break-up of Gondwana.

5 – Compressive phase of the North Omani margin : Subduction then obduction

The mid-oceanic ridge is located, according to the Panalesis model, at 3880 km off Oman. Unlike all the other models (*e.g*. Pillevuit *et al*., 1997 (their fig.2) ; Breton *et al*., 2004 (their fig.8) ; Duretz *et al*., 2016 (their fig.1a) ; Ninkabou *et al*., 2021 (their fig.2b)), when the ridge fails, it is not the Omani obduction that takes place, but a ‘ classic ’ intra-oceanic subduction (Fig.05). Indeed, when the oceanic lithosphere of the East Gondwana/Africa plate subducts under the Semail plate, the oceanic crust will be eclogitized. The lithosphere then sinks under its own weight, and a slab roll-back phenomenon can subsequently occur (Vérard, 2019.a). With the eclogitization of the crust of the lower plate however, there is hydration of the mantle under the upper plate, and the formation of an arc ; this is called intra-oceanic subduction. The slab roll-back makes it possible to bring the arc closer to the North Omani margin (*i.e*. to fill the 3880 km ; Fig.05), and a new mid-oceanic ridge is set up at the back of the arc and accompanies the movement. The Omani seamounts, located on the passage of the arc, are detached from their basement and incorporated into the accretionary prism of the subduction zone (see examples of this phenomenon in Dominguez *et al*., 2000). In our opinion, most of the major rotations defined on the basis of palæomagnetism (up to 120° according to Weiler, 2000 and Godard *et al*., 2003) occurred at this time. When the intra-oceanic arc collides with the North Omani margin in the mid-Cretaceous (Fig.06), the ridge located a few hundred kilometers behind the arc fails and allows “ the real Omani obduction ” to occur (Fig.07 ; Vérard & Stampfli, *in prep*.). The Semail plate then passes over the lithosphere carrying the intra-oceanic arc (“ fore-arc block ” in Fig.07.d3), then over the Omani passive margin. Contrary to the model of Breton *et al*. (2004), we do not believe that the rupture of the whole lithosphere at the level of the Omani passive margin is possible (see also Fig.03).

We rather favour a decoupling between crust and lithospheric mantle in accordance with the models of Shemenda (1993) and Boutelier & Chemenda (2011). Elements of the passive margin (*e.g.* Jebel Akhdar, Saih Hatat; see Fig.07.d6) undergo high degrees metamorphism at depth and then return back to the surface (see also Python *et al.*, 2020). With the detachment of the slab in the Palæocene, the entire margin is uplifted and creates the exhumation structures well-described by Breton *et al.* (2004) for example. The lithosphere carrying the arc is now totally "lost". Behind, the Semail plate itself is consumed by a subduction zone under Eurasia (Iran). Nowadays, in Zagros (Fig.07.a), the Semail plate is also entirely "lost" (Fig.07.c2) but not yet completely around the Gulf of Oman (Fig.07.c1).

Finally, we also consider that the gap between the series of the Jebel Akhdar and Saih Hatat zones is indeed associated with a transfer fault ("Semail Gap Transfer Zone") as proposed by Ninkabou *et al.* (2021), but we do not associate this shift with a difference in extension of the Omani continental crust. We rather propose that this shift is the consequence of the presence or not of the oceanic plateau/ magmatic margin (the "Panjal Plateau" in Fig.02.a), which was formed in the Permian during rifting in connection with the Panjal Traps (see "extensive phase"). The Semail Gap Transfer Zone is thus for us an indicator of the maximum lateral extension (along the margin) of this hot spot volcanism (Fig.02).

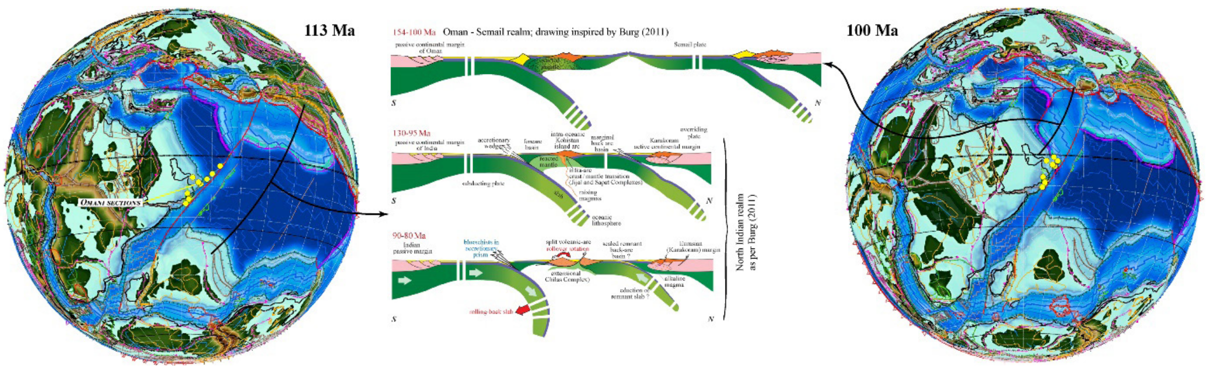

Fig. 05. Palæogeographic reconstructions (Panalesis.v.0) around 113 Ma [*i.e.* Aptian – Albian boundary, *long-normal superchron*] and 100 Ma [*i.e.* Albian – Cenomanian boundary, *long-normal superchron*]; The geodynamic scenario for the Oman – Semail region follows that of the India – Kohistan scenario proposed by Burg (2011) and used in Vérard *et al.* (2017).

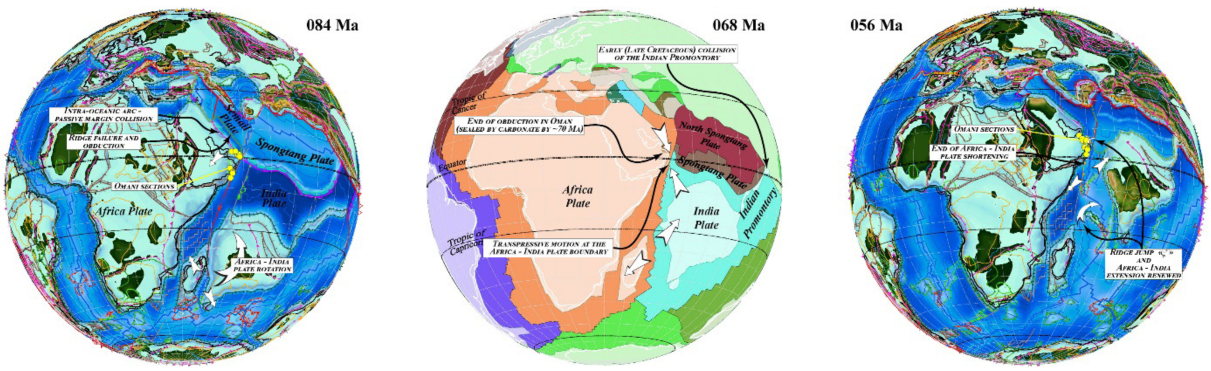

Fig. 06. Palæogeographic reconstructions (Panalesis.v.0) around 84 Ma [*i.e.* Santonian – Campanian boundary, *magnetic anomaly C34*] and 56 Ma [*i.e.* Thanetian – Ypresian boundary, *magnetic anomaly C25*]; The plate tectonics model (random colours) highlights transpression along the east-omani margin in the context of the Madagascar – India divergence and the collision of the Indian Promontory with Eurasia (Vérard *et al.*, 2017).

6 – Transpressive phase of the East Omani margin

At the end of the Lower Cretaceous, the mid-oceanic ridge, which was located in the Mozambique Channel and Somali Basin, jumps and becomes located between India and Madagascar. The India plate then slides south-southeast of the Africa plate. According to the pre- and post-Long Normal Superchron marine magnetic anomalies in the Indian Ocean (specifically the M0 [Aptian] and C34 [Santonian–Campanian] anomalies ; Müller *et al*., 2008 ; Eagles & Hoang, 2013), and according to the geometries of the India and Africa plates, a transpressive motion occurs along the eastern Omani margin when India begins its northward migration (after its separation from the Antarctica plate). With the Panalesis model, we suggest that the motion of the India plate relative to the Africa plate along the East Omani margin initially corresponds to a strike-slip mouvement (' classic ' transform fault), and that the transpressive phase occurs from about 75 ± 5 Ma when the Indian Promontory (Vérard *et al*., 2017) collides with Eurasia and allows exchanges of fauna between India (the ' biotic ferry ' of Hedges, 2003) and the continent.

The East Omani margin then underwent a shortening reaching up to 250 km (perpendicular to the margin) according to Panalesis, creating the metamorphism on the Masirah Island and the Batain Mounts (Schreurs & Immenhauser, 1999). We also assume a sliding (parallel to the margin) of the order of 90 km of the *tectonic element* (see term in Vérard, 2019.a,b), which carries the sections of Massirah, Asselah, Sal, and Jebel Aweri (Fig.01).

During the Oligocene (*e.g*. Stampfli *et al*., 1991), Arabia separated from Africa by slab-pull effect under Iran. In the Indian Ocean, the Carlsberg mid-oceanic ridge extends northward through a transform fault that runs along the East Omani passive margin. With the motion of the Arabia plate and the formation of the Red Sea and Gulf of Aden rifts, this transform fault enters into compression (Fig.08). We hypothesize that an oceanic plateau – wichi we name the Owen Plateau – was formed as the northern extension of the Chain Ridge (located south of the Socotra Island) at the time of the ridge jump between the magnetic anomaly C31 (*ca*. 68 Ma) and C25 (*ca*. 56 Ma) and the abandonment of the Seychelles on the Africa plate. We propose that the transpressive boundary between the India and Arabia plates does not convert into a " true " subduction zone due to the locking of the Owen Plateau, in the style of the Ontong-Java or Hikurangi plateaus in the present-day world. In the Panalesis model, this " arc-plateau collision " however leads to a displacement, estimated at 123 km, of the *tectonic element* which carries the sections of Massirah, Asselah, Sal, and Jebel Aweri (Fig.08). The marine magnetic anomaly C05B (Langhian) proves that the mid-oceanic Sheba ridge skirts the area where we place the Owen Plateau, and branches into the current Owen Fracture Zone. This phenomenon is similar to a ' subduction jump ' from the front of the plateau locked at the East Omani passive margin towards the rear of the plateau, whose margin is a zone of rheological weakness (Vérard, *in prep.*). The Owen Fracture Zone is not, however, a " true " subduction zone (which is why one cannot really speak of a ' subduction jump ') since its movement is predominantly sinistral.

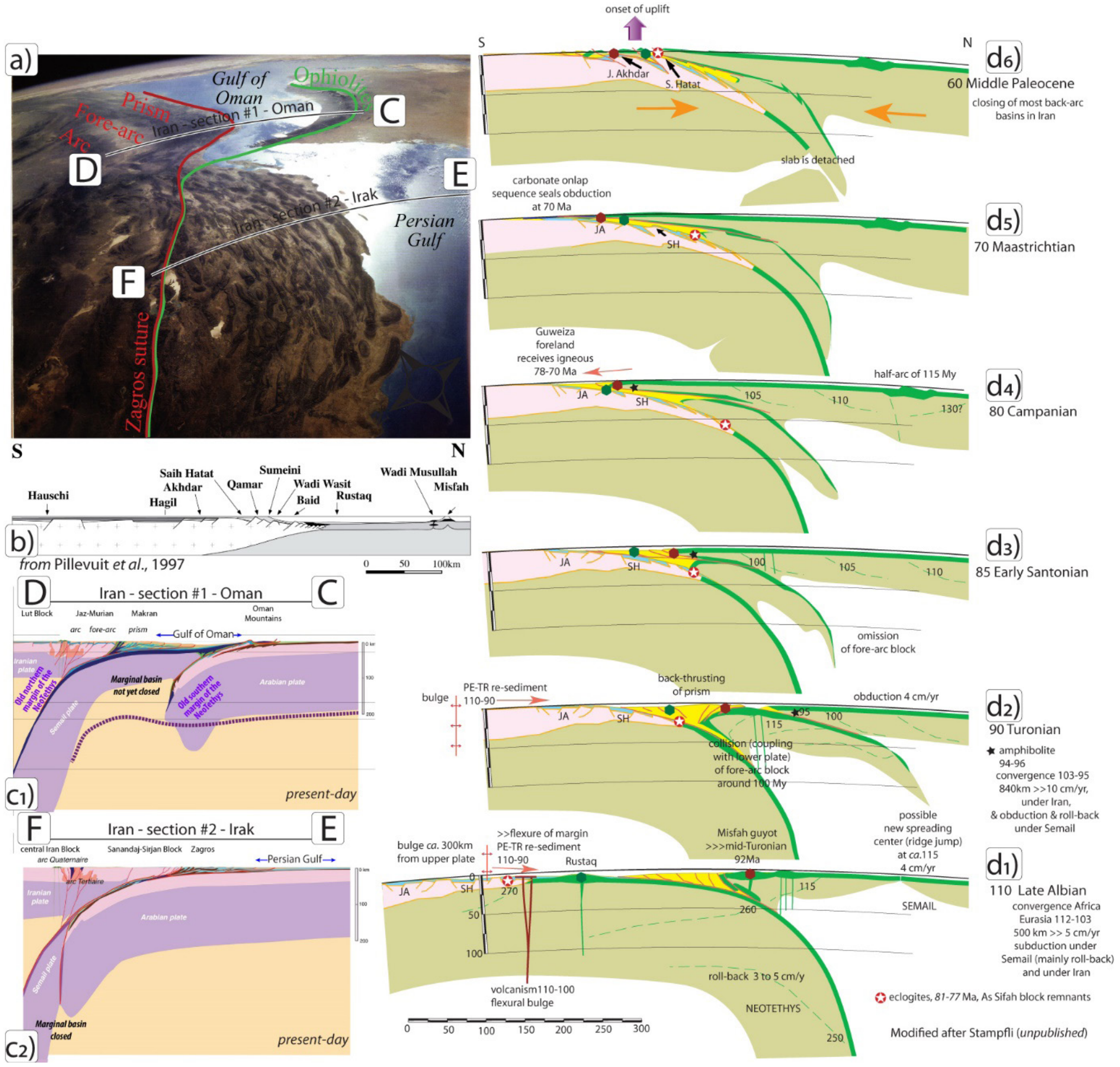

Fig. 07. Geodynamic environment related to the Omani obduction; a) *Upper left panel*: Satellite view (towards the South-East) of the Iran – Oman area, with cross-sections (C-D and E-F) shown in c); b) *Middle left panel*, after Pillevuit *et al*. (1997), showing a reconstruction of the Arabian passive margin of the NeoTethys in the Permian (prior to the Cretaceous obduction); c) *Lower left panel*: Lithospheric cross-sections corresponding (c1) to section C-D and (c2) to section E-F shown in a); d) *Right panel*: Evolution model from *ca*. 110 Ma to 60 Ma after Stampfli (2005-*unpublished*).

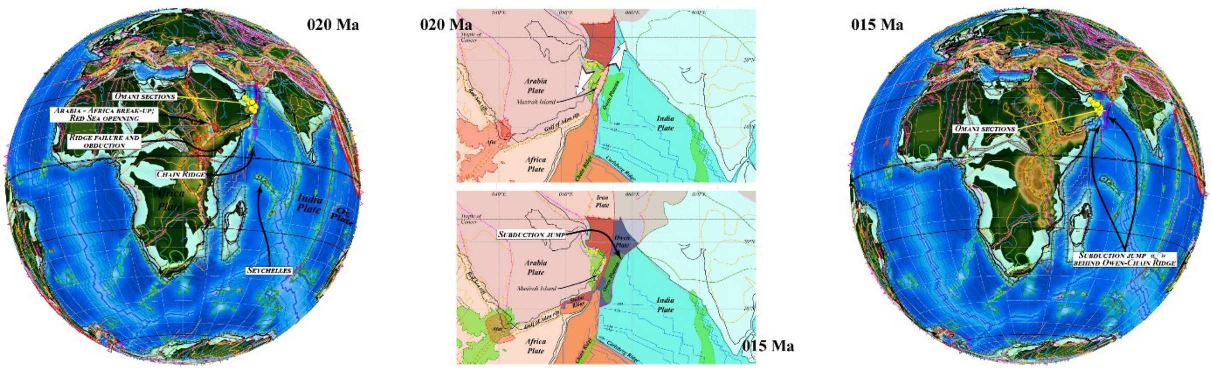

Fig. 08. Palæogeographic reconstructions (Panalesis.v.0) around 20 Ma [*i.e*. Burdigalian, *magnetic anomaly C06*] and 15 Ma [*i.e*. Langhian, *magnetic anomaly C05B*]; The plate tectonics model (random colours) at 20 Ma and 15 Ma highlights the proposed arc – plateau collision and the subduction jump behind the Owen Plateau, as well as the associated displacement of the Masirah *tectonic element* along the east-omani margin.

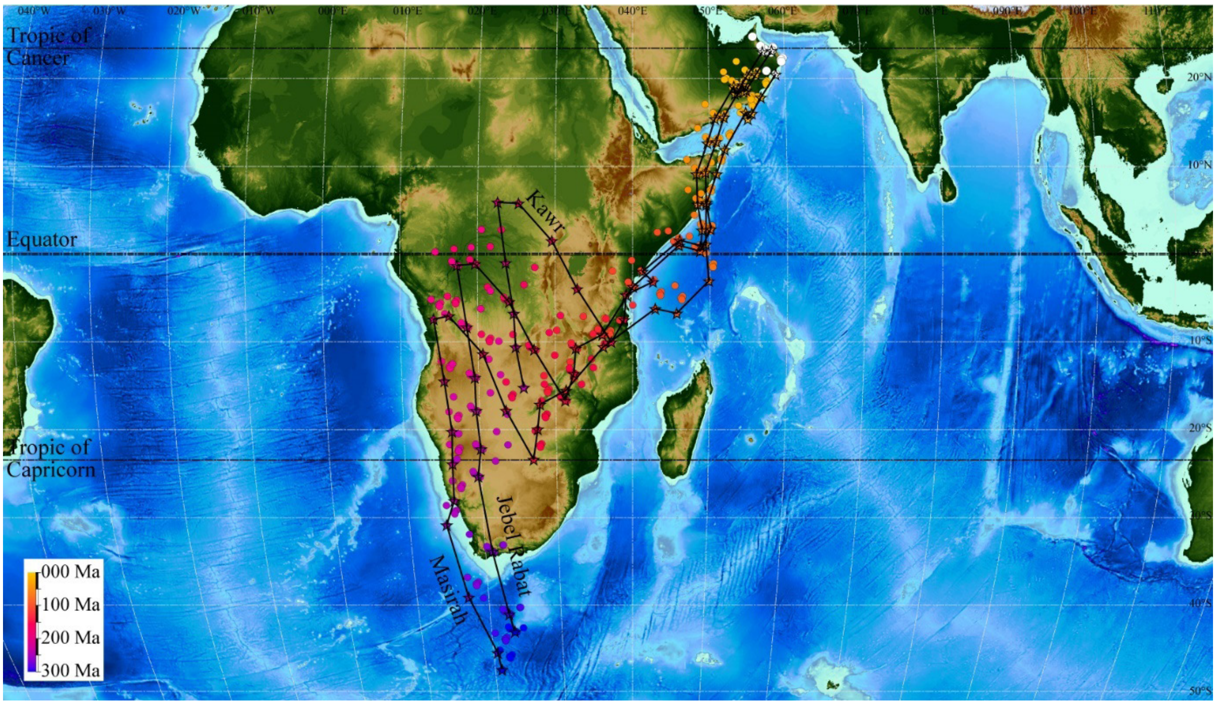

Fig. 09. Palæoposition of the considered sections from 300 Ma to present-day (see scale for colour-coded ages); for sake of clarity, only three evolution paths – for Masirah, Jebel Rabat, and Kawr – are shown.

7 – Conclusions

The analysis of various sections associated with the Panalesis global model of plate tectonics made it possible to characterize the palæopositions (Fig.09), the palæogeographies, and the geodynamic history of the northern and eastern margins in Oman. In particular, we highlight the following points:

1. Part of the sections of the North Omani margin formed on the Panjal Plateau, a plateau/ magmatic margin emplaced on the style of the Etendeka/Walvis Ridge plateau/ magmatic margin in the present-day world, explaining in particular the gap in the shortening between the Jebel Akhdar and the Saih Hatat zones, and the presence of the Semail Gap Transfer Zone of Ninkabou *et al*. (2021).
2. Unlike other models, we argue that the Omani obduction did not begin with the NeoTethys ridge failure. This ridge failure, located 3880 km from the Omani margin, caused a 'classic' intra-oceanic subduction zone. The migration of the arc by slab roll-back effect cross-cut the seamounts and basalts from the Hawasina basin and caused the strong rotations recorded by palæomagnetism. It was at the time of the arc – continent collision that the "true" Omani obduction was set up by ridge failure of a new mid-oceanic ridge formed at the back of the arc.
3. The Eastern Omani margin underwent a major phase of transpression (with up to 250 km of shortening), which formed the Eastern Ophiolites Bets of the Masirah Island and the Batain Nappes during the motion of the India plate relative to the Africa plate. The ridge jump, coeval with the abandonment of the Seychelles on the Africa plate, released the constraints on the Omani margin. We hypothesize that this ridge jump was also guided by hot spot volcanism at the Chain Ridge, which we extend to the north by an oceanic plateau, the Owen Plateau.
4. This Owen Plateau, which will have to be evidenced in the future, allows us to explain: a) the failure of the development of a "true" subduction zone from the transform fault which limited the Arabia plate and the India plate; b) the displacement of the Masirah *tectonic element* along the East Omani margin; c) the 'subduction jump' (or transpressive fault jump) on the current Owen Fracture Zone.

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Connecting the dots : tracing the impact of permian paleoclimate on environmental changes of southern Gondwana's Tethys margin (Pakistan)

Wadood, Bilal

The formation of Pangaea supercontinent resulted in global warming and widespread development of dry-to-arid greenhouse climates during Permian. Tectonic upheaval shifted warm surface water from low to high latitudes and created cold-water upwelling on western coast of Pangaea. Massive mountain building processes severely affected regional and local climates, thus developing endemic biological realms. The southern Gondwana margin experienced climatic change due to tectonic expansion of Neo-Tethys and rifting induced basaltic extrusion. To better comprehend the Permian climate evolution and its impact on paleoenvironmental changes at the southern margin of Gondwana (NW margin of Indian Plate), here we utilize Middle to Late Permian strata exposed in Salt Range and Trans-Indus Ranges (Pakistan).The Middle Permian (Wordian) strata exhibit coarse-grained, ripple-marked, channelized sandstone and fossiliferous limestone suggesting deposition in a tide-influenced subaqueous delta under the fluctuating sea level. The compositionally mature sandstone in the lower part of the strata coupled with various geochemical proxieshintreworking of detritus from the adjacent rift shoulders under thewarm humid subtropical climate. The presence of a temperature-sensitive fusulinid fauna in association with photozoan-based ooidsand the deposition of limestone facies in the upper part confirms the Middle Permian warming.The overlying Capitanian-Wuchiapingian pure fossiliferous limestone strata show diverse depositional environments ranging from mudflats and lagoon to sand shoal and middle shelf. Thus a marine Tethyan setting wasestablished at the margin of the rift flank basin with strong local intra-plate stresses. The outcrop studies of the overlying Changhsingian strata show laterally variable thicknesses of dominantly thick-bedded, calcareous and fossiliferous sandstone and sandy limestone. While the petrographic, geochemical, and SEM studiesdivulged lagoonal to delta dominated middle shelf evironment of deposition with an extremely arid and cold climate. The deposition of Changhsingian clastic-rich carbonates on the underlying pure carbonates (Capitanian-Wuchiapingian) hints strongly towards a sea-level fall on the NW margin of the Indian Plate. Such end-Permian regression tightly correlates with the stratigraphic record of the adjacent continents, including South China, the Persian Gulf, and northern Gondwana regions.

Griesbachian to smithian ammonoids from northern indian margin, with a review on the current state of knowledge of early triassic ammonoid biostratigraphy, evolution and biodiversity dynamics through this interval

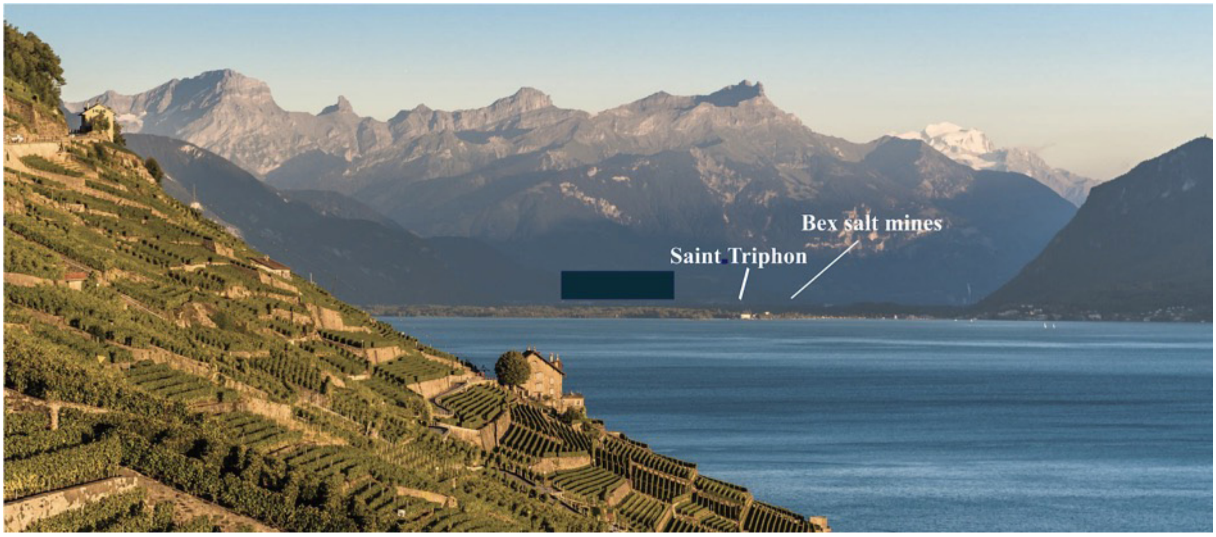
Ware, David & Dai, Xu

Until recently, most of our knowledge of Triassic biochronology and correlations was based on ammonoid faunas. Nowadays, conodonts also play a major role due to their more widespread, less facies-dependent occurrence. Nevertheless, recent investigations in the Griesbachian to Smithian of the Salt Range (Pakistan) and Spiti valley (Himalaya, India) have shown that ammonoid-based biostratigraphy provides higher time resolution than conodonts, and as such remain crucial for our understanding of the timing of the recovery following the Permian-Triassic mass extinction. Recently, the re-sampling of two previously known localities and sampling of two other new outcrops spanning this time interval in South Tibet allowed the validation and improvement of the biostratigraphic scheme previously proposed for the Northern Indian Margin, together with cross-correlation with conodont biostratigraphy and carbon isotope curves. The corresponding global correlations will be presented, together with some reflections on the corresponding stage and sub-stage boundaries.
The talk will be concluded by a short presentation of our current understanding of ammonoid taxonomy, evolution and biodiversity pattern through and following the Permian-Triassic mass extinction. Early Triassic, and particularly Induan ammonoids, remain to this day poorly known due to two reasons: the remote location of important expanded outcrops with well-preserved material (e.g. Siberia, Arctic Canada, NE Greenland, and central Himalaya) or to geopolitical complications (e.g. Pakistan, Afghanistan, central Himalaya, Madagascar). The perspective and priorities of these areas would be interesting to re-investigate in detail will be discussed.

Field trip guidebook : Local Triassic outcrops from carbonate platform to evaporite

September 2, 2023

By Aymon BAUD[1],



From Lavaux to Rhone Valley with the main stops in white. Lac Léman "Lake Geneva" on the right. The snow-capped "Grand Combin" (4314m. high) in the background and the Morcles thrust sheet Crest ("Hautes Alpes calcaires", Helvetic domain) in the back

CONTENTS

References

1 – Introduction

Part of the Alps and the foreland basin will be crossed by our field trip. Limestone, gypsum, landslide siliceous carbonate pebbles and clay, marls carbonates and sandstone are composing the main terroirs of the tasted wines.

1.1 – Western Switzerland geological setting

According to Trümpy (1980): "Alpine rocks fall into two categories: a pre-Triassic or pre-Pennsylvanian basement complex, affected by the Variscan (Hercynian) and older orogenies, and Triassic to Lower Oligocene sediments which were only deformed by the Alpine (mid-Cretaceous to Pliocene) movements". The Pennsylvanian and Permian continental sediments occupy an intermediate position. At higher and intermediate structural levels, basement and cover complex show quite different tectonic behavior; in many instances, the cover-rocks have been stripped away from their basement substratum, to form detachment nappes of their own. At deeper structural levels, Alpine deformation and metamorphism have largely obliterated the original differences of competence and of structure, so that the basement and cover complex were deformed conformably. Mesozoic subsidence, rifting and spreading produced the Piemont ocean with an intraoceanic platform, of which the Briançonnais rise is the most prominent one. At the same time, the northern (Helvetic) and southern (Austro-alpine-South Alpine) margins were shaped. New oceanic crust was produced from mid-Jurassic to end-Cretaceous time (Fig. 1).

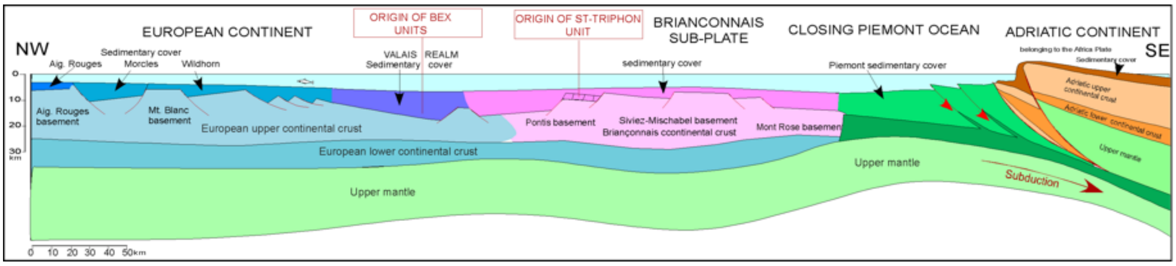


Figure 1 : Middle Cretaceous (100 Ma) geological section with original position of visited outcrops in the Prealps. The European units are getting closer of the Adriatic micro-plate of African origin and, with the subduction, the Piemont oceanic belt is closing. There were no Alps at that time ! (adapted from A. Escher, in Baud et al., poster 2012).

Crustal shortening, producing folds and nappes (Fig. 2), began at the end of the Lower Cretaceous and went on until the Pliocene, with an interruption during the Paleocene. The orogenic phases were accompanied and followed by metamorphism, which reached high amphibolite grade in the deepest exposed parts of the Alpine edifice. Synorogenic plutonism and volcanism remained rather modest.

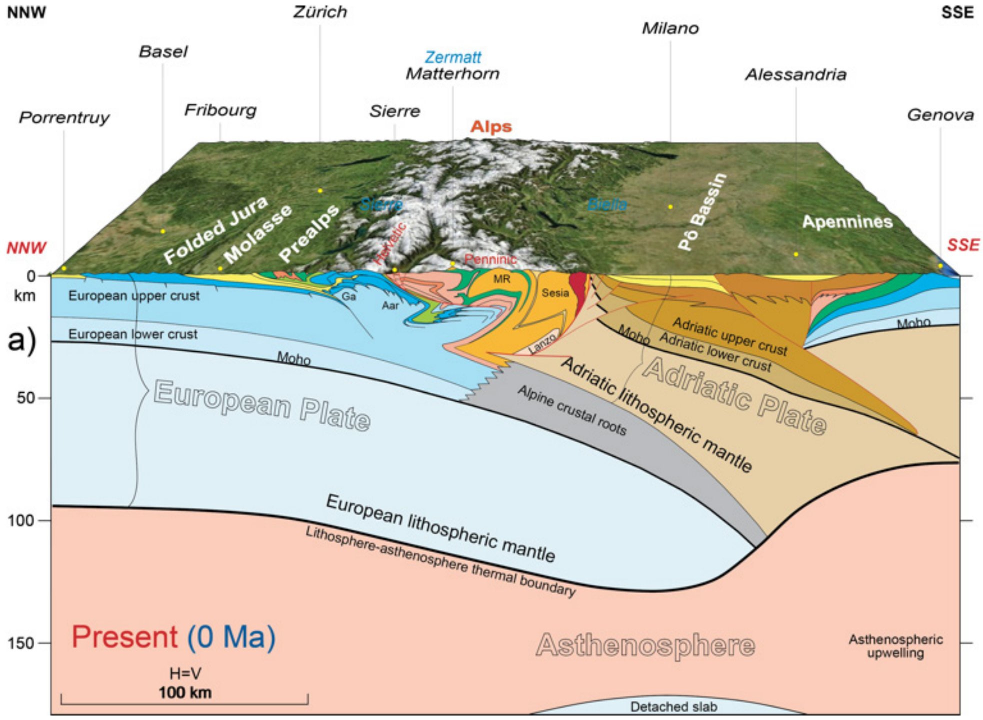


Figure 2 : Block diagram of Western Switzerland from Apennines to folded Jura through the Alps. (R. Marchant, in Guidebook FTB 2, 19th International Sedimentological Congress 2014).

1.2 – The Triassic carbonate and evaporite of Western Switzerland Prealps

The shallow Triassic seas are related to two domains. From the north, the Germanic Muschelkalk basin encroached on the Helvetic realm ; from the Southeast, the transgression of the Paleotethys, which had been restricted in Late Paleozoic times to the southeastern most part of the future Alps, covered the Austroalpine and most of the Briançonnais realms.

Lower Triassic formations are invariably terrigenous, rich in quartz grains and poorly fossiliferous. Middle Triassic carbonates reach their maximum thickness in the Briançonnais belt (Fig. 3). A change in paleogeographical pattern occurs in the Late Ladinian. During Late Triassic times, two broad facies belts can be distinguished : the “ Zone des Cols ” (Ultrahelvetic and “ Sub-Mediane ” Mélange, Figs. 3 and 4) with a great amount of evaporites (with salt cement, area of Bex) and the intertidal to supratidal carbonate platform of the Blond Dolomite followed by well-developed Rhaetian limestone to the southeast (Fig.4).

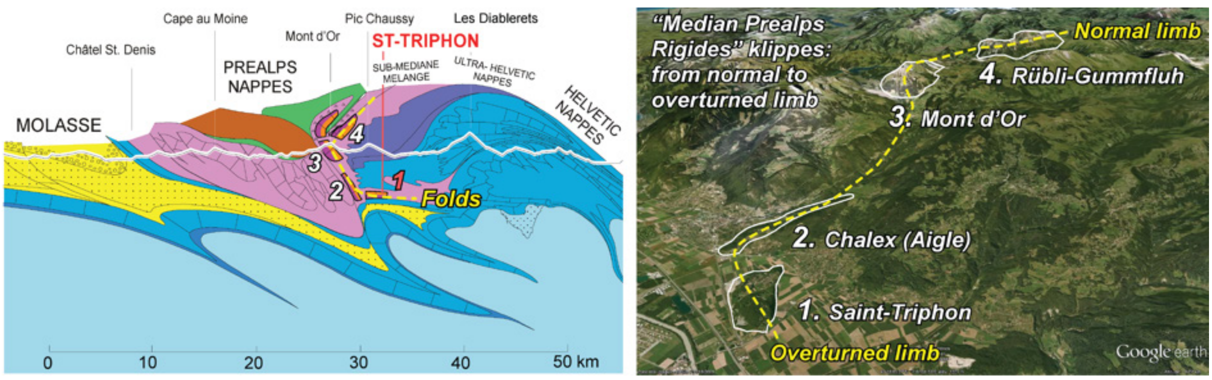


Figure 3 left : Geological cross-section from Molasse to Helvetic nappes. The Saint-Triphon hills are lying in the overturned part of the large Sub-Mediane Melange fold ; right, “ Google Earth ” view with the position of the Mediane klippes from normal to overturned limb (adapted from A. Escher, in Baud et al., poster, 2012).

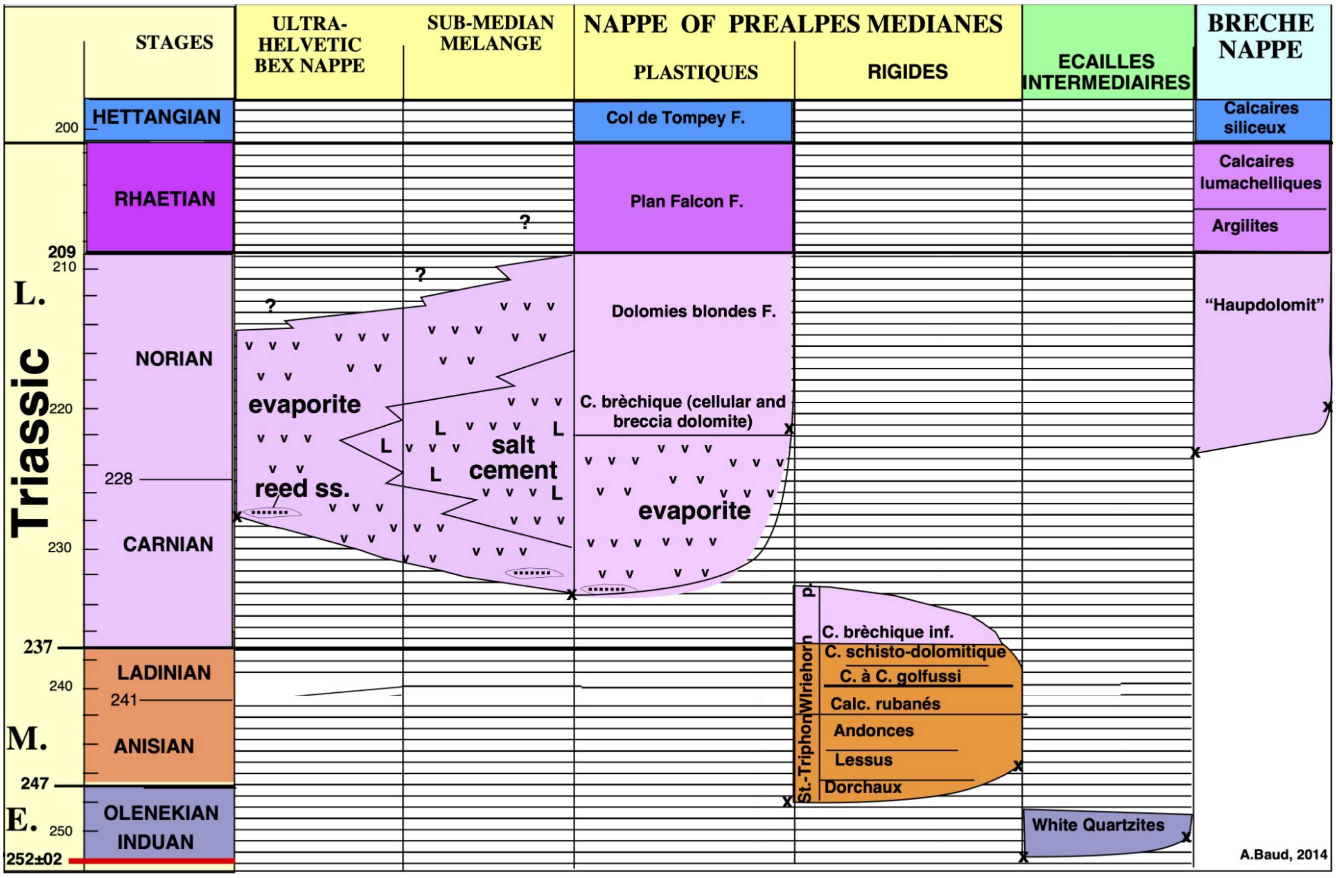


Figure 3 : Sketch of the Triassic Units within the Western Switzerland Prealps (adapted from Baud in Mégard-Galli & Baud,1978). During the fieldtrip, we will look at the Anisian limestone of the Saint-Triphon Formation (Prealpes Medianes Rigides tectonic unit, Baud, 1972) and at the Late Triassic Evaporite of the "Sub-Mediane" Mélange (Salt mine of Bex).

1.2.1 – The Anisian Saint-Triphon Formation, (Baud, 1987, fig. 5, Baud, 2022).

The visited Saint-Triphon Formation is a formally established Early Middle Triassic lithological unit of the Prealps and of the Briançonnais realm of the Western Alps. The type locality occurs in the vicinity of the village of Saint-Triphon in the Rhone Valley of Western Switzerland. Subdivided in 3 Members and 19 levels, this Formation, 220 m thick in the type area, consists of 5 main shallowing upward carbonate cycles. Lying at the base of the internal part of the Prealpes Medianes Nappe ("Préalpes médianes rigides"), the Saint-Triphon Formation is also cropping out all along the Briançonnais domain of the Western Alps, from the Barrhorn area (N of the Matterhorn) to the Ligurian Alps in the S.

The palinspastic reconstruction of the Middle Triassic marine area shows that the shallow marine carbonate deposits occur in an intra-cratonic subsident half-graben of estimated 500 km length and 100 to 150 km width. Its orientation was to the NE and E in relation to the actual alpine trend. During the time of the Saint-Triphon Formation deposit, the more subsident area was emplaced in the original position of the "Préalpes médianes" and the calculated rate of sedimentation is 100m/Ma. This rate decreases from a 2/3 ratio in the direction of the Ligurian Alps with an average there of about 30m/Ma.

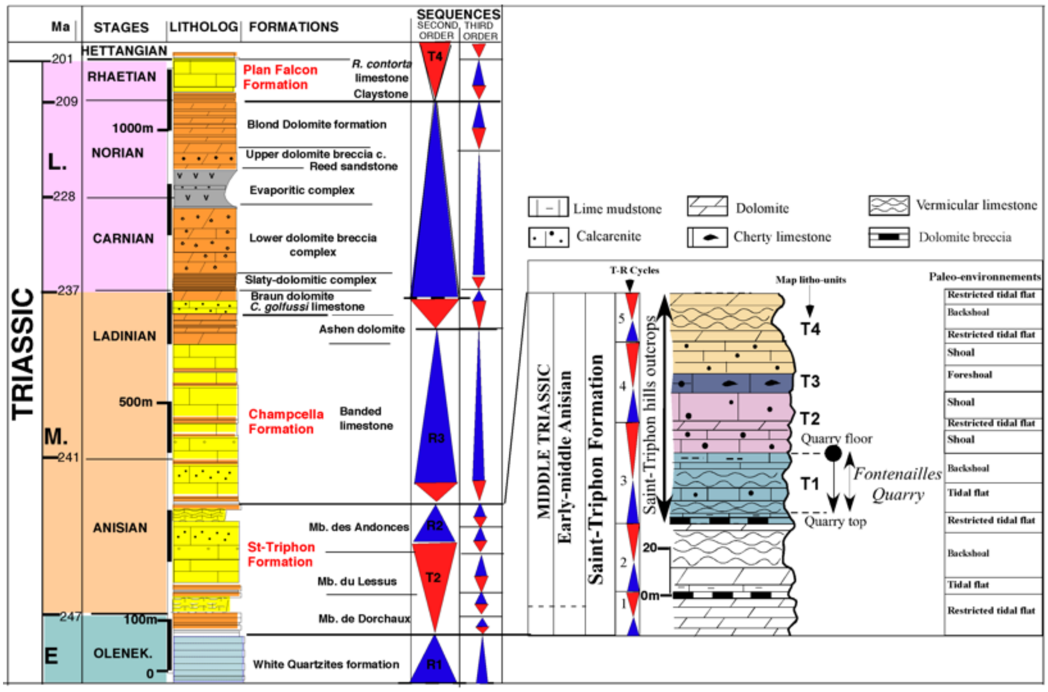


Figure 5 left : Composite Triassic section of the "Préalpes Medianes" Nappe with second and third order sequences (Baud, 1972 and 1987) ; right, composite Saint-Triphon Formation section from the type locality area (after Baud in Baud et al., 2012).

The dynamic aspect of the Saint-Triphon Formation carbonate deposits and the faciès models are presented through the 3 main stages of shallow water carbonate platform development :

A. the birth and initial development stage occurs during the end of the Early Triassic and the Anisian start and is characterized by a multi-phased transgression of the peritidal dolomites followed by the shallow ramp - lagoonal vermicular limestone ;
B. after an important eustatic regression and emersion of the platform, the early stage (Early to Middle Anisian) is represented by a complete tidal flat succession ;
C. during the mature stage of the carbonate platform (Middle to Early Late Anisian), the depositional model consists of 4 main paleoenvironnments (Fig. 6) : 1-the coastal plain, 2- the tidal flat - backshoal, 3- the "barrier" consisting in lime sand shoals and patch algal-sponge mounds, 4- the foreshoal.

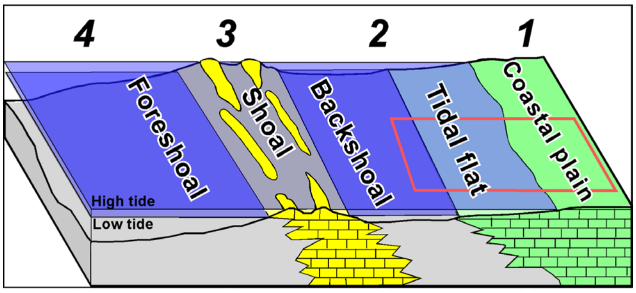


Figure 6 : Paleoenvironments sketch of the mature carbonate platform stage. Explanations in the text (Baud, 1987).

1.2.2 – Paleoecology and timing of the middle Triassic microbial mats to sponge-microbial buildups, and bio- events in the Briançonnais epeiric sea, links to the Permian–Triassic crisis aftermath.

Recent works on classic stromatolite (Lee & Riding, 2020), on sponge take over following the end-Permian mass extinction (Baud et al., 2021) and the possible extension of the sponge-microbial buildups in the Germanic basin Triassic carbonate (Pei & Reitner, 2022), led us to question and actualize the so called “algal mats, crypto-sponge and mudmound” of our published work on the middle Triassic carbonate of the neighboring Briançonnais epeiric sea (Baud, 1987; Baud et al., 2016). In this adjacent sea, recorded from central Switzerland to Franco-Italian maritime Alps, a first marine transgression occurred during the Lower-Middle Triassic transition about 247 My ago, characterized by a very large scale, dolomitic microbial mat deposition (a, fig. 7) a first similarity with the post extinction basal Triassic stromatolites of the Tethys. But the presence of nonspicular demosponges in the Briançonnais stromatolites with a mutualistic relationship is here to be resolved.

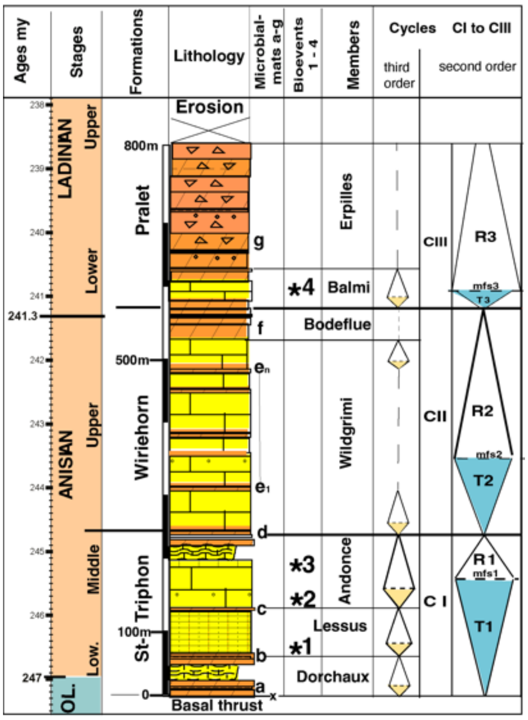


Figure 7: Stratigraphical sketch of the Middle Triassic succession of the Briançonnais domain in Western Switzerland with microbial mats levels and bioevents. Captions: limestone in yellow and dolomite in braun. T=transgressive system-track; R=regressive s-t; mfs=main flooding surface; Absolute ages in millions of years (My) according to recent chronostratigraphic charts.

During the Lower Anisian time (247-246 My), a new, large scale dolomitic microbial mat, caps (b, fig. 7) the open shallow marine deposition of the 20m thick vermicular limestone of the Dorchaux Member. The next third order transgressive cycle (Lessus Member) is showing a first bio-event (*1, fig. 7) with the lower Anisian sudden recovery of abundant calcareous algae, which disappeared during the end-Permian great extinction and were absent during Early Triassic time. At the top this Lessus Member (middle Anisian about 246 My ago), a local dolomitic microbial mat was well recorded (c, fig. 7). The new transgressive system track of the Andonce Member brought two bio-events (*2 and *3, fig. 7): the first concerns the resurgence and abundance of siliceous sponges, bio-event at the origin of the first chert bands in the limestones. Due to an Ammonoid finding, the second bio-event is well dated of the middle Anisian *B. cadoricus* zone and consists of the recovery of a corals type *Thamnastrea*, and of calcareous and non-calcareous spicular sponges' growth. Also, unique and close in time, a level of a thrombolitic buildup up to 4 m thick were found in the Rothorn section, all described in Baud, 1987, "mudmound" showing similarity to the post extinction basal Triassic sponge microbial buildups (Baud et al., 2021).

At the middle-upper Anisian transition between 245 and 244 My ago, the regressive top of the Saint-Triphon Formation is characterized by a very large scale, dolomitic microbial mats deposition (d, fig. 7) recorded within the whole Briançonnais domain. The overlying Wildgrimmi Member of the Wiriehorn Formation consists of a 220 to 340 m succession of peritidal carbonate deposits with a shift to pluri-metric scale shallowing-upward cycles, each topped by a dolomite bed possibly of microbial origin (e1 to en, fig. 7), like to same age South Alpine lagoonal Latemar shorter cycles. The upper regressive part of the Wiriehorn Formation is characterized by dolomitic beds partly built by stromatolites (f, fig. 7). In the following transgressive part of the Pralet Formation, the recorded conodont *trumpyi* allowed us to date the upper bio-event (*4 *fig. 7*) of the basal Lower Ladinien, about 241 My ago. It consists of a short living rich assemblage of crinoids, gastropods, brachiopods, bivalves, and siliceous sponges. Then due to aridity and higher salinity, the carbonate factory moves to dolomitic production with increase in microbial activities (g, fig. 7) and loss of skeletal material in the upper Pralet Formation still Ladinien in age (240-238 My).

1.2.3 – The Late Triassic evaporite and Salt.

The Salt mines of Bex, North of the Bex Village known since 1684, are still in activity and provide all the salt needed by the county of Vaud and the chemical industries of Monthey. The salt is included in a huge mass of Upper Triassic anhydrite, belonging to Sub-Mediane Mélange Zone (Fig. 8), which covers a large area north and northeast of Bex Village.

The anhydrite (gypsum at the surface) contains Triassic inliers of dolomite, green dolomitic shale, black shale and sandstone, and thick but discontinuous intercalations of fossiliferous Liassic limestone, of Aalenian shale and of Eocene flysch. This complex is folded in such a wild manner that, in spite of the numerous galleries, shafts and borings of the mines, the structure is only partially understood.

The evaporite and salt deposits occurred during the upper Triassic time (partly Carnian) within an aborted rift, Dead Sea like, between the Briançonnais sub-plate and European plate (Fig. 9).

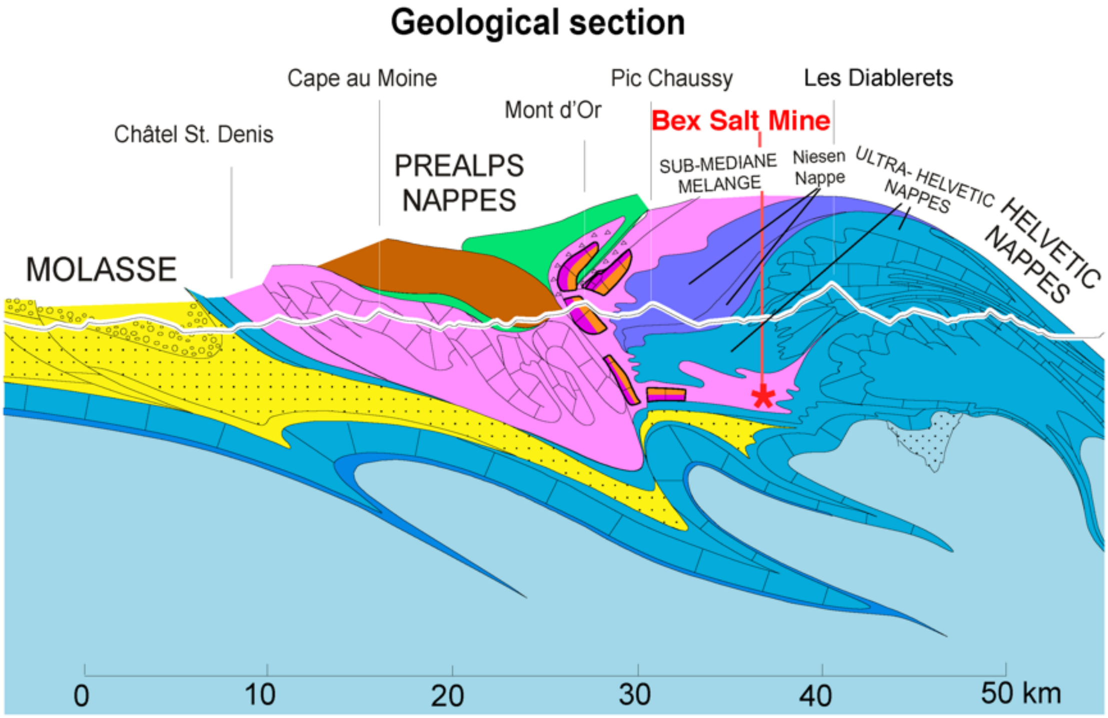


Fig. 8 : Geological section (NW-SE) through the Western part of the Swiss Alps along the Rhone valley (adapted from A. Escher in Baud et al., poster, 2012).

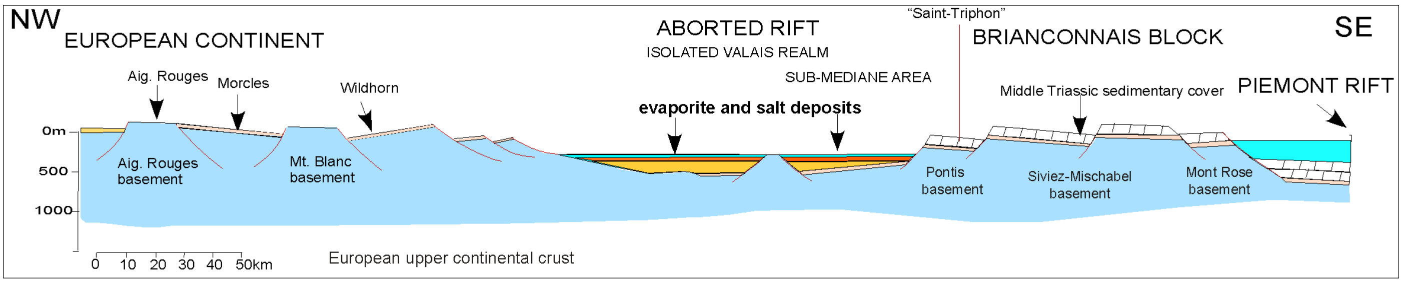


Fig. 9 : Late Triassic geological sketch with the original position of the evaporite basins (A Baud).

2 – Geological itinerary and stops (Figs. 10 and 11)

The Saint-Triphon hills, which host the Formation stratotype, are home to some of the most fascinating outcrops in the Briançonnais region of the Western Alps, not only in terms of the history of geological sciences, but also in terms of the history of georesources in the Vaud region, with the exploitation of ancient quarries described and illustrated by Pradervant and Baud, (2007). There are also unique and educational outcrops for teaching earth sciences and continuing education. A large panel of geological explanations has been installed in the Fontenailles quarry at the instigation of the Fondation Nicole Debarges (Baud et al., 2012).

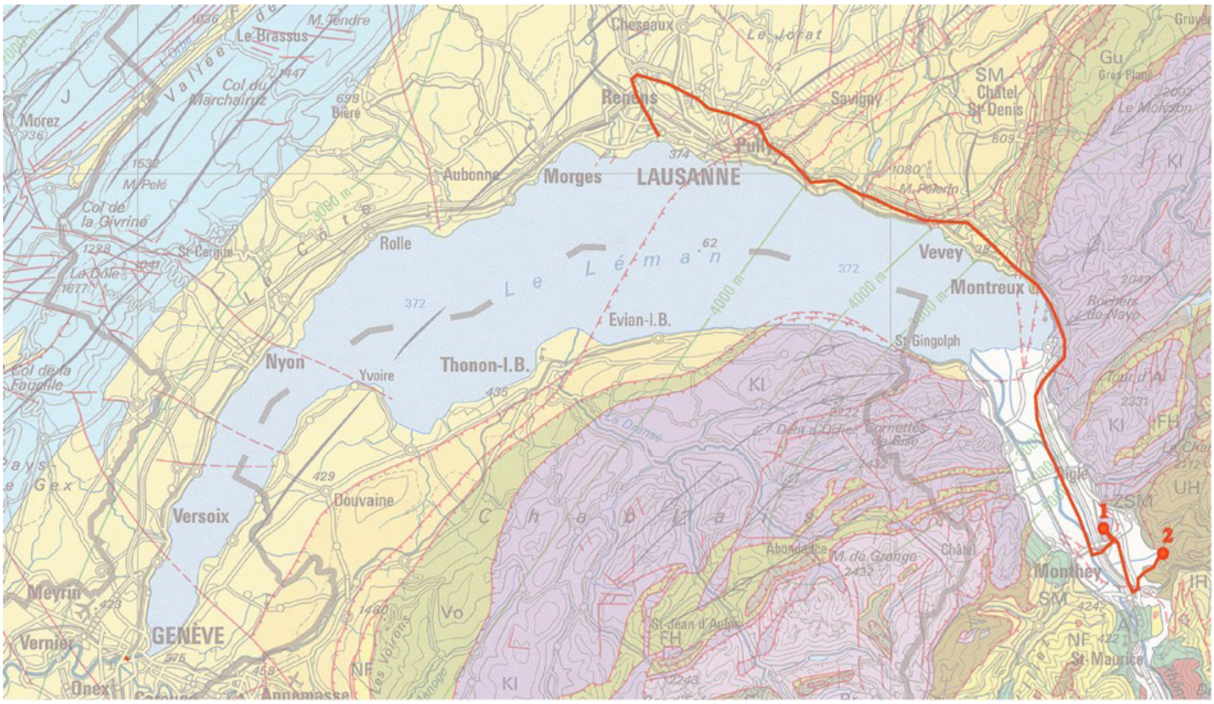


Figure 10 : Tectonic map of Western Switzerland with, in red, the itinerary and the two stop places ; stop 1, Saint-Triphon, Fontenaille quarry ; stop 2, visit of the Salt mine of Bex.

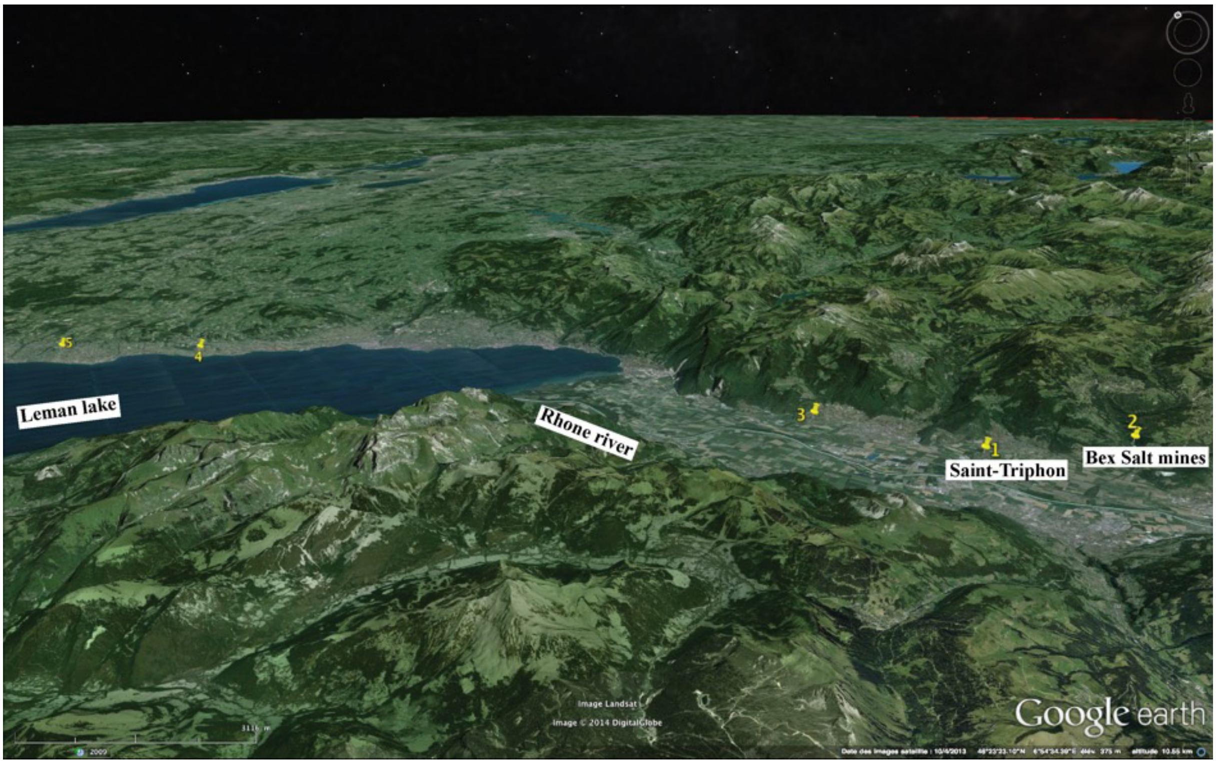


Figure 11 : Google Earth oblique view with the five main stops of the day as presented in the map above.

2.1 – Stop 1 : Saint-Triphon, Fontenaille quarry (A.Baud, Figs. 12 to 15)

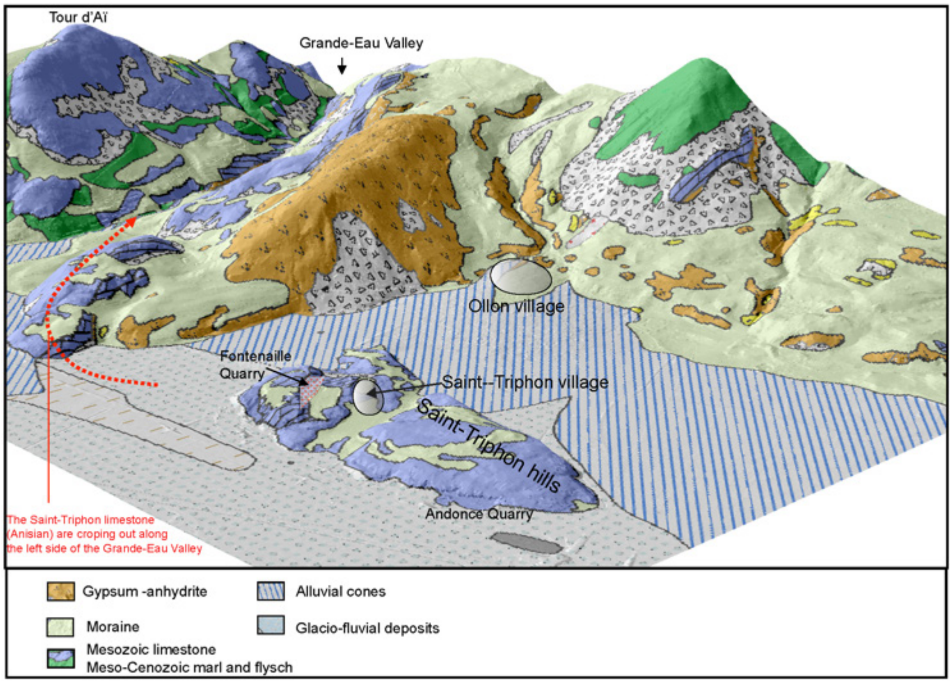


Figure 12 : Geological map of the Saint-Triphon area on a 3D relief (adapted from Giorgis. 2012)

The first stop of our Fieldtrip is the lower Anisian limestone of the Fontenaille quarry in the Saint-Triphon hills. The main geological settings are given in the introduction. The geology of this overturned limestone klippe is shown on hills map (Fig. 29) and detailed geological sections have been worked in each quarry along the hills. A composite section of the hills compared to the main Prealps Triassic composite section is given at the Fig. 28 .

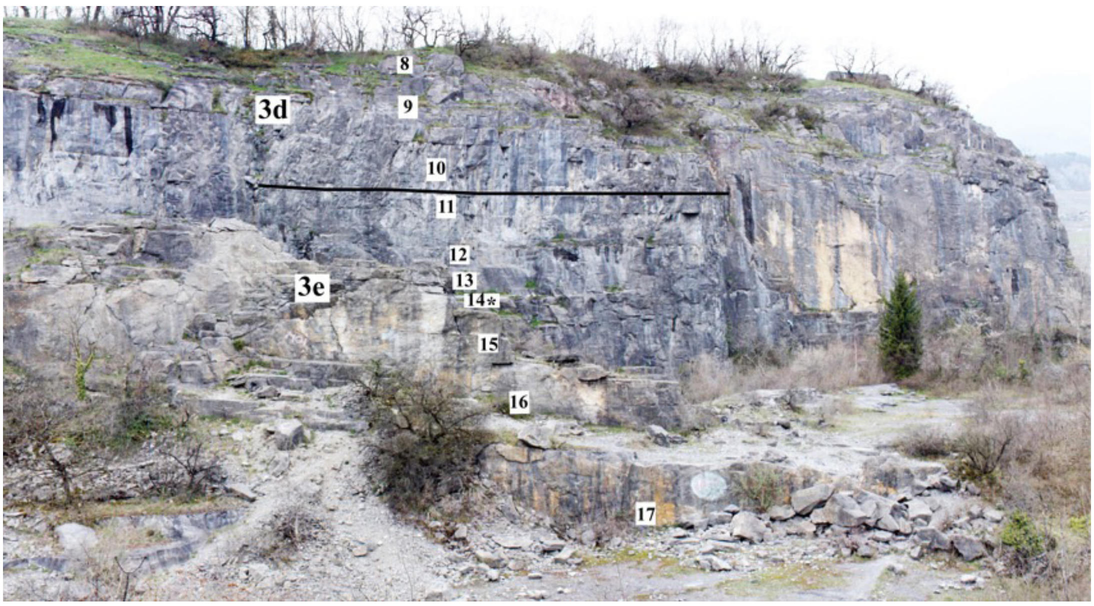


Figure 13 : Stop 1, the Fontenaille quarry with overturned middle Anisian limestone ; the units 3d and 3e and the bed nombers8 to 17 refers to the lithological section shown at the Fig. 14.

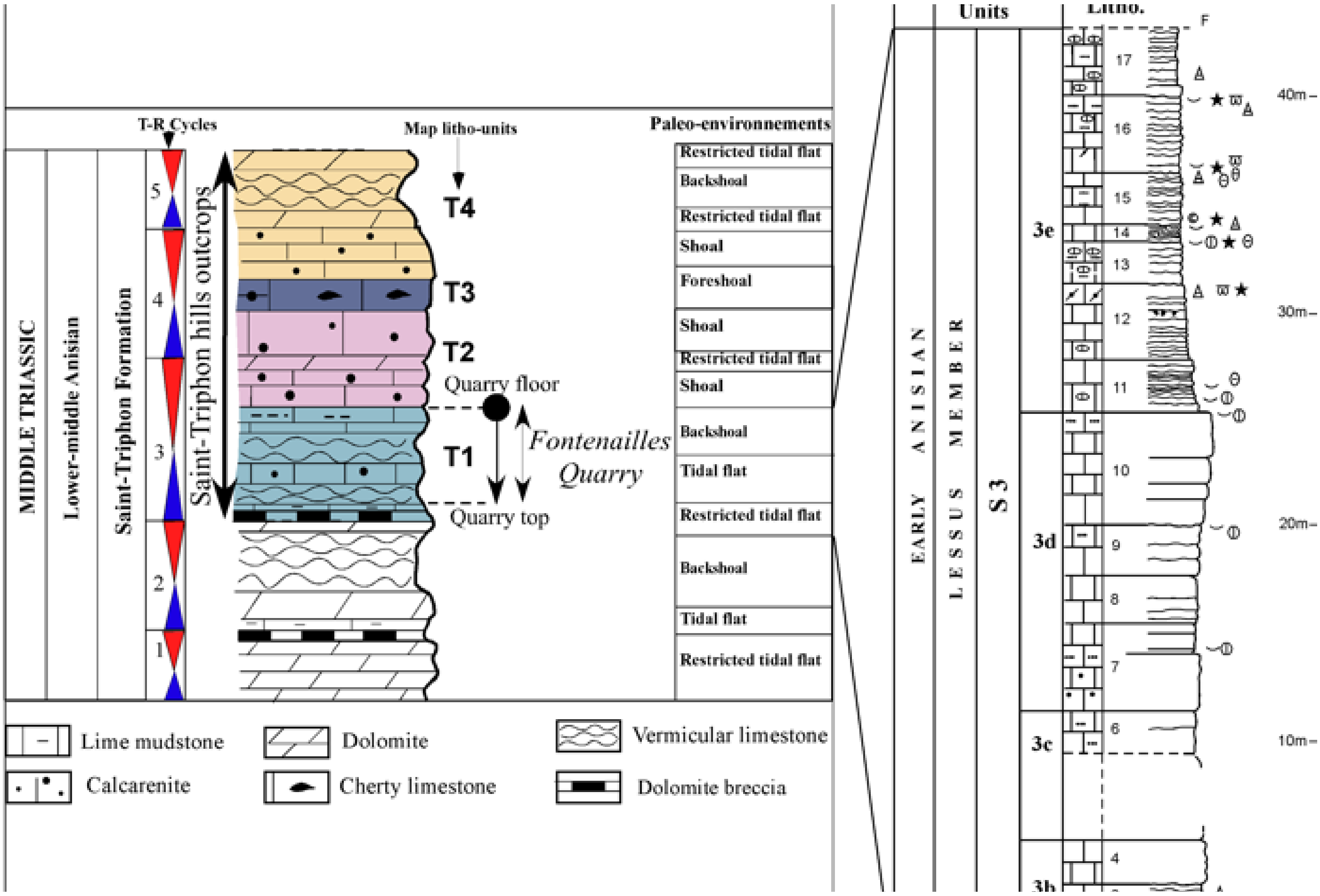


Figure 14 : Composite Saint-Triphon Formation section from type locality area on the left (adapted from Baud et al., 2012). The color of the lithological units T1 to T4 are the same as in the geological map below (Fig. 15) ; on the right is the lithological section of the Fontenaille quarry (Baud, 1987) ; the bed numbers are reported on the quarry wall picture Fig. 13.

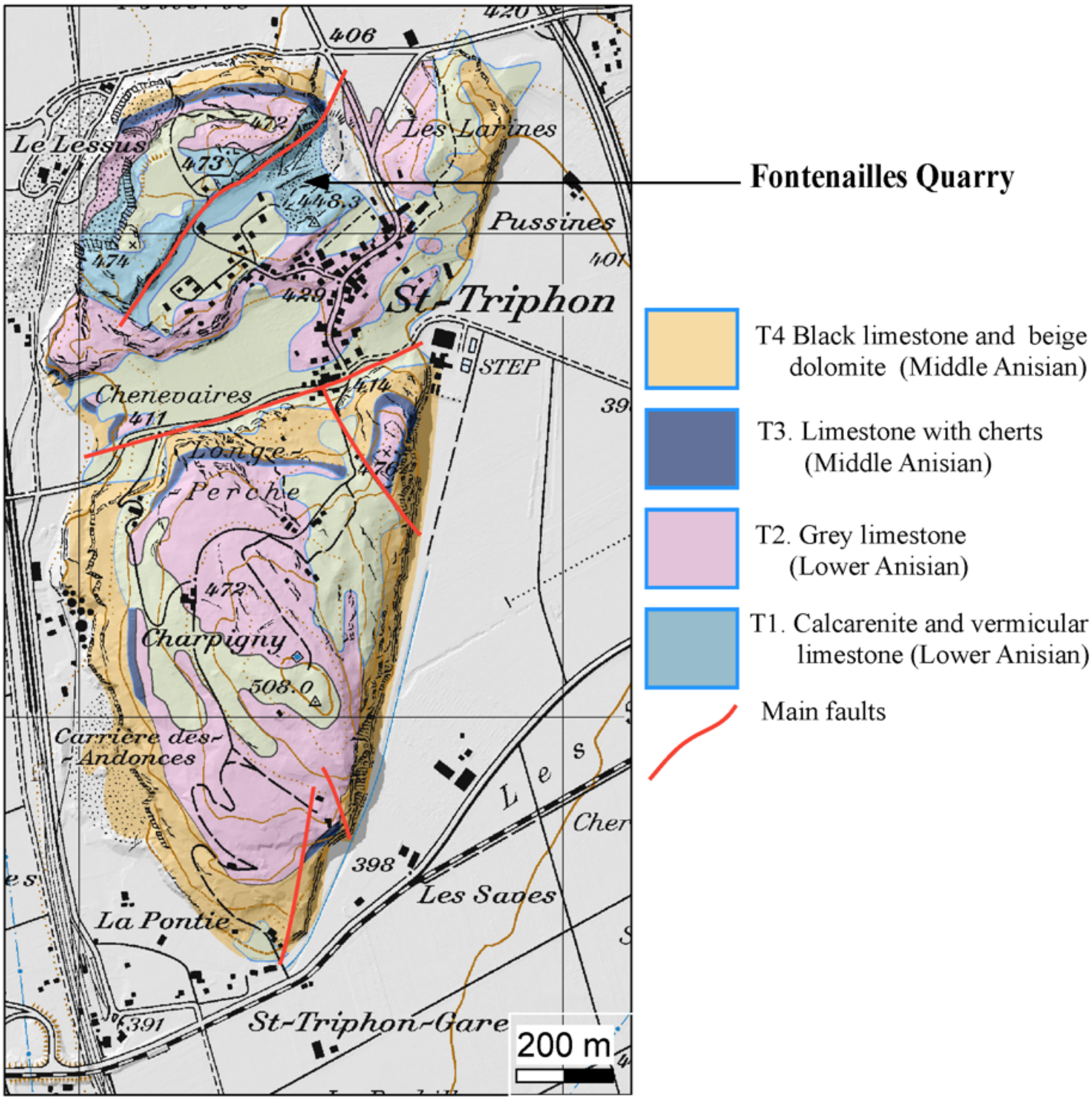


Figure 15 : Detailed Geological map of the Saint-Triphon hills, from Badoux, 1962, colored in Baud et al., 2012).

After looking at the geological explanation panel in the quarry (Poster of Baud et al., 2012), we will move to a typical "calcaires vermiculés" surface (Fig. 16). These shallow water facies have a wide distribution in the lower and middle Triassic epeiric seas west of the Neotethys (Baud, 1976). The burrowing activity is here due to *Spongeliomorpha* types of burrows. The organisms which produced these burrows are Decapods (Crustacea). Their presence is confirmed by *Palaxius* and *Favreina* types of coprolites in the surrounding rocks. Decapods were very sparse at the end of the Paleozoic, but at the beginning of the Mesozoic, they apparently underwent explosive development due to favorable ecological conditions in these shallow water seas. In this way, they strongly influenced the early diagenetic environment and consequently the rock facies.

A detailed description of this facies and of the trace fossils are given in Baud, 1976 (in french). Below, the Figure is showing burrowed overturned bed surface as we can see in the NW part of the quarry (bed 12, Figs. 13 and 14).

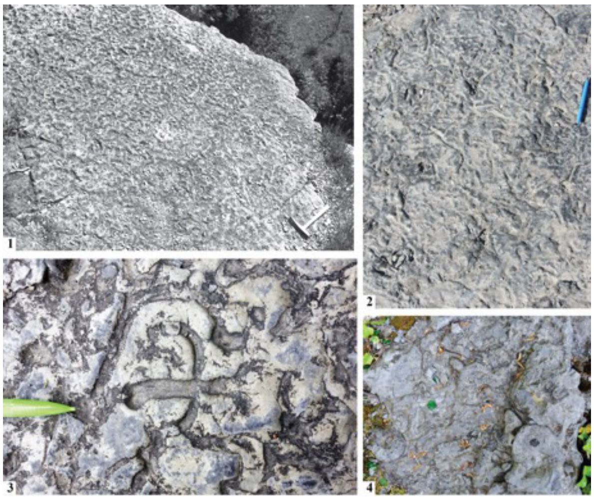


Figure 16 : The vermicular limestones ; 1- vermicular surface near the top of the Fontenaille quarry with Spongeliomorpha suevica trace fossil ; 2- surface in the middle part of the quarry with thiner Spongeliomorpha network ; 3- detail of the branching burrows ; 4- Rhizocoralium jenense burrows from the younger unit 5 in the Andonce quarry (photos A. Baud).

After examining the "calcaires vermiculés" surface, we will move and discuss the deformational structures due to overpressure on unstable soft and partly cemented lime deposits (Baud, 1987).
These deformational structures (Figs. 17 and 18) appear in the shallow ramp to lagoonal rythmicaly layered lime-mud sediments. Vertical, "en chevron" and sigmoidal slab joints, pseudo-folding, crumpled beds and pseudo-breccia or conglomerate are illustrated, and 2 processes of the synsedimentary deformations are analysed. These processes are influenced by reversed viscosity gradients and by the "soft" and "hard" layers thickness ratio. My first interpretation (Baud, 1987) was the overpressure by fair weather giant waves but now I think that the earthquake shaken is a better hypothesis.

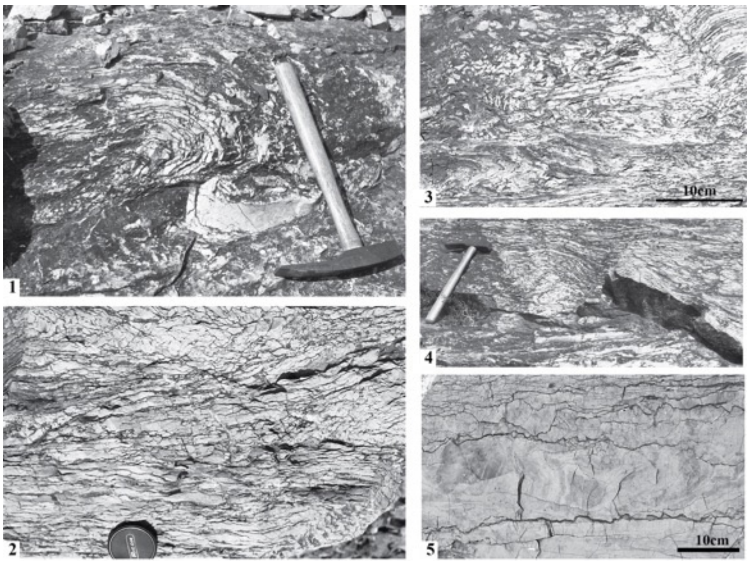


Figure 17 : Seismite soft-sediment deformations ; 1- Recumbent fold, horizontal micro-fault and disrupted lime mud layers ; 2- disrupted and pinch-and-swell layers ; 3- gentle fold inclined over disrupted layers and recumbent fold ; 4-disrupted and brecciated layers ; 5- Soft lime mud injected and folded by disrupted layers (photos A. Baud).

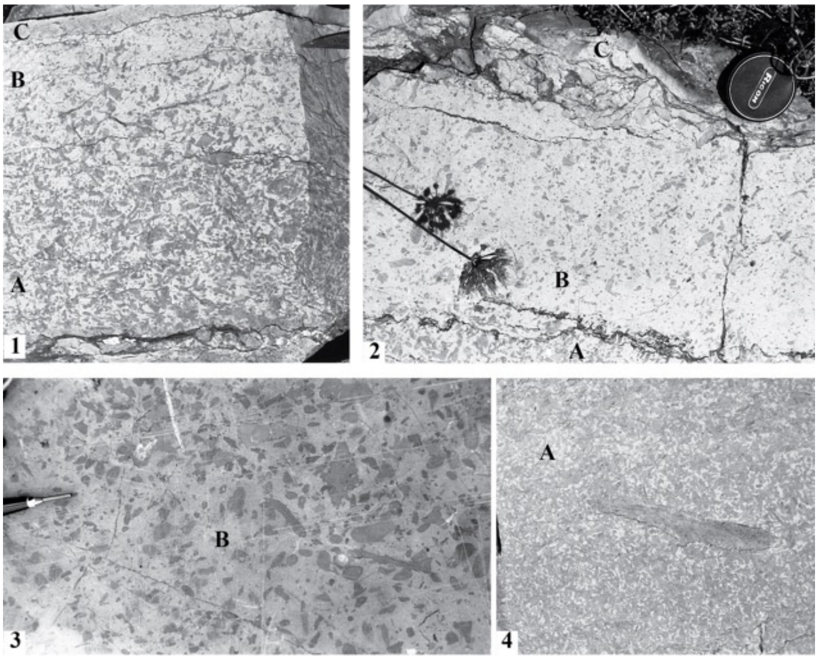


Figure 18 : Seismites, liquefaction of the vermicular limestone matrix ; 1- graded deposition (A, B) of the semi-solid burrow clasts in the quasi-liquid lime-mud matrix (thixotropic shock) ; 2- detailed view of the upper part with high matrix ratio (B), the top level C is showing an erosive base with re-deposit of large lime clasts (tsunamite ?) ; 3 and 4 : detail view of the burrow and lime clasts, less packed in 3 and more densly packed in 4 (photos A. Baud).

2.2 – Stop 2 (11h15-12h) : the large quarry named Andonce

It is in the second quarry visited, near the Railway station (carrière des Andonces). This quarry comprises the upper part of the Saint Triphon Formation, the sequences S4 and S5 (Fig. 19). In the upper part of the quarry. the top of S4 shows calcarenites stratified with current megarides. Most of the walls takes place in S5 : the black limestones of Saint- Triphon are rich in organic matter. in places, they are strongly bioturbated by decapod crustaceans (*Rhizocorallium*. *Spongeliomorpha*) (A. Baud, 1976).

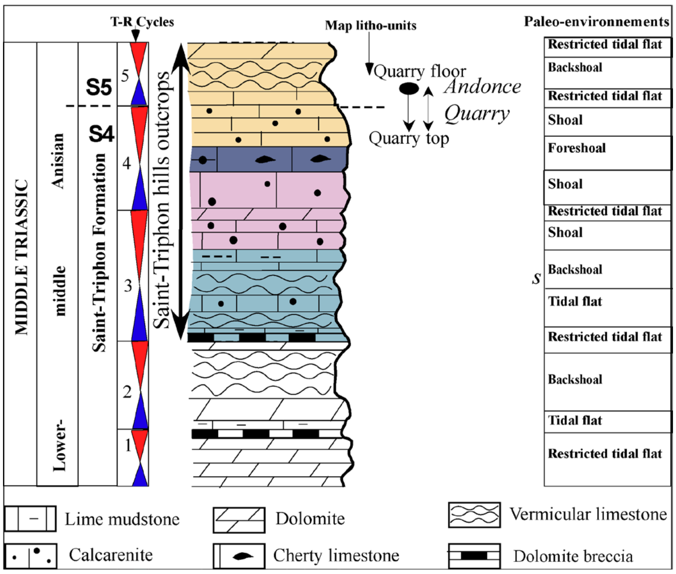


Figure 19 : Composite Saint-Triphon Formation section from type locality area (adapted from Baud et al., 2012).

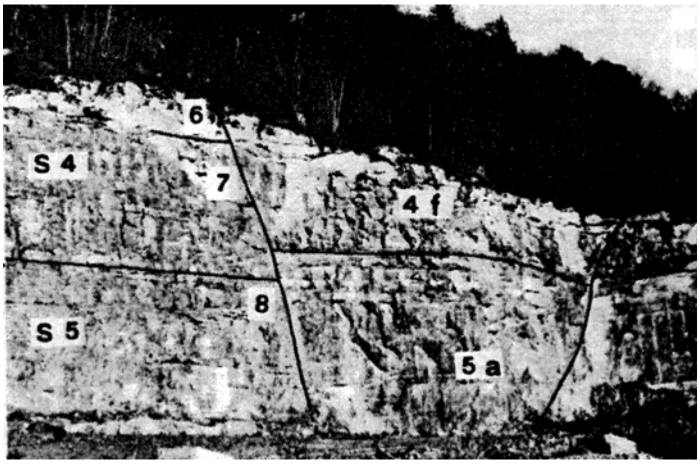


Figure 20 :Andonce Quarry, East wall with overturned middle Anisian limestone ; the units S4 and S5 refers to the lithological section shown at the Fig. 19. (photos A. Baud).

At the base of the East wall, microsequences of storms - centimetre-thick granoclassed calcarenites - alternate with spicule calcilutites. Halfway up the wall, there is a remarkable level of true *Coenorhyris vulgaris* lumachelle with celestine filling (SrS0 4). Blocks of it were found at the foot of the wall.

Following the quarry's railroad line for a hundred meters or so, we reach the artificial West wall described in 1975 by A. Baud and H. Masson who proved an uplift of several hundred of meters of the Briançonnais at the end of the Liassic and beginning of the Dogger times, in an extensionnal – transtensional regime, on the base of paleokarstic and paleotectonic analysis. Modelling the geodynamic of the Alpine Tethys opening, several authors came much later to conclusion of an uplift of the briançonnais shoulder of the rift, not reminding that it was first discovered in the quarry of Saint-Triphon !

Numerous horizontal stylolitic joints are intersected by small conjugate faults (fig. 21, left). On two of these, triangular channels recording paleokarst (fig. 21,right), filled at the base with fine material (dolomitic sand and silt), while dolomitic pebbles and gravels are confined to the upper part. This surprising arrangement is easily explained by the fact that the series is inverted.

Figure 21 :Andonce Quarry, west sawed-of wall. Left : stylolitic joints intersected by small conjugate faults. Right : Karst conduit (15 cm thick) with granoclastic filling in overturned position !

2.3 – Stop 3 (14h30-16h00) : Bex : visit of the Salt Mine (Figs. 22 to 27)

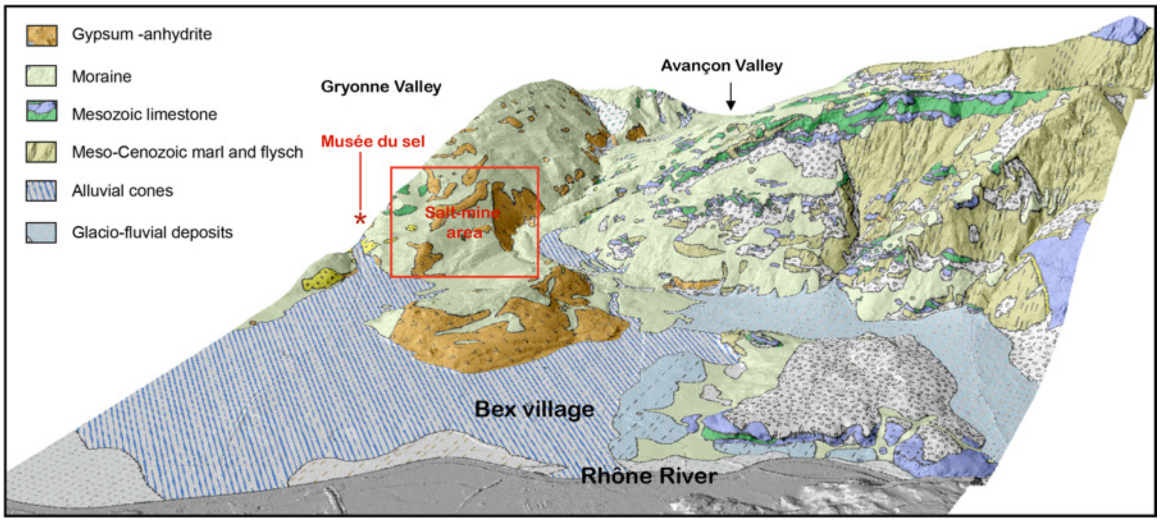


Figure 22 : Geological map on 3D relief topography (adapted from David Giorgis maps, 2012)

The main geological setting is given in the introduction. The salt is included in a huge mass of Upper Triassic anhydrite, belonging to Sub-Mediane Melange Zone, which covers a large area north and northeast of Bex Village (Fig. 23).

4.1 – Resumed approach to the geology of the mines

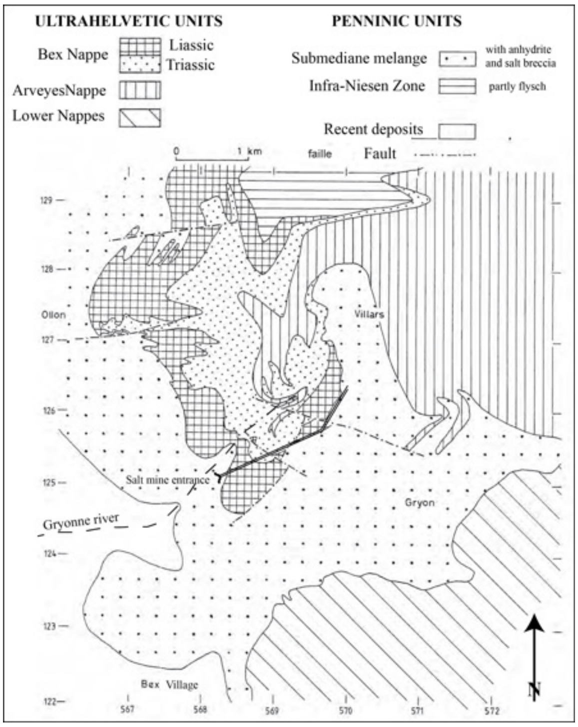


Figure 23 : Tectonic map of the Salt mines area adapted from Graf, 1993 ; the trace of the visited gallery is shown in the middle of the map.

This stop 3, after the lunch time will be given to the underground visit of the Bex salt mine. Below (Fig. 24) is a picture of the main panel near the entrance of the mine, with the gallery topography and the main underground rooms.

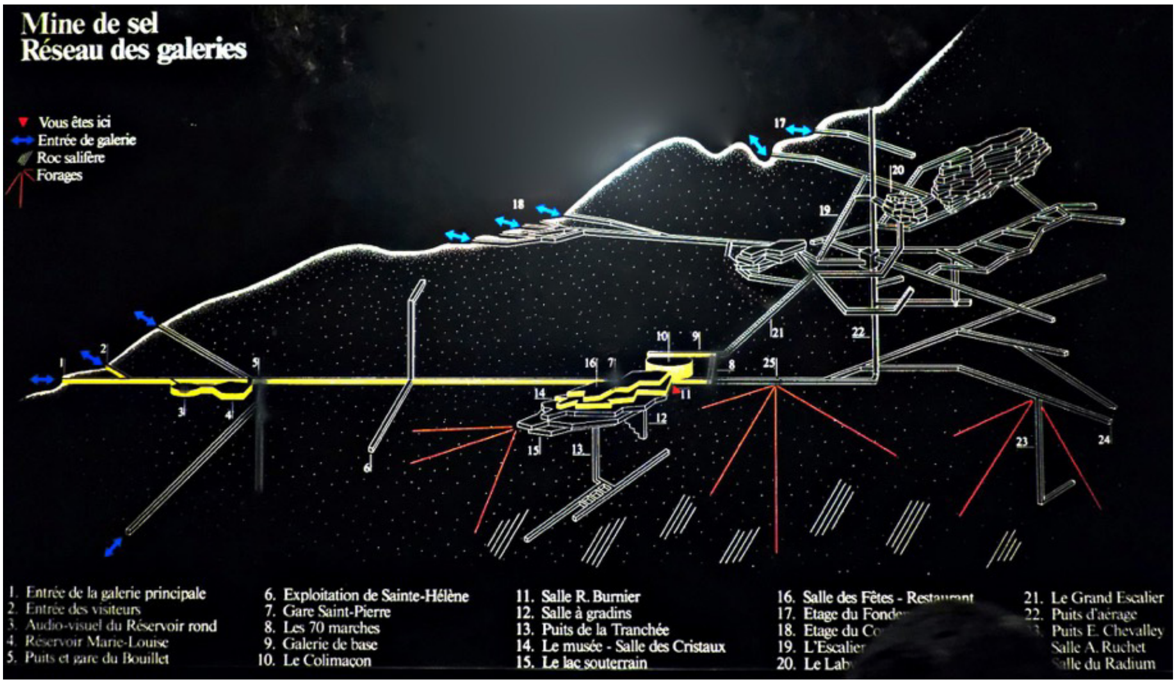


Figure 24 : The gallery network of the Bex salt mines (the visited gallery is in yellow)

A geological cross section of the visited gallery is given below (Fig. 25)

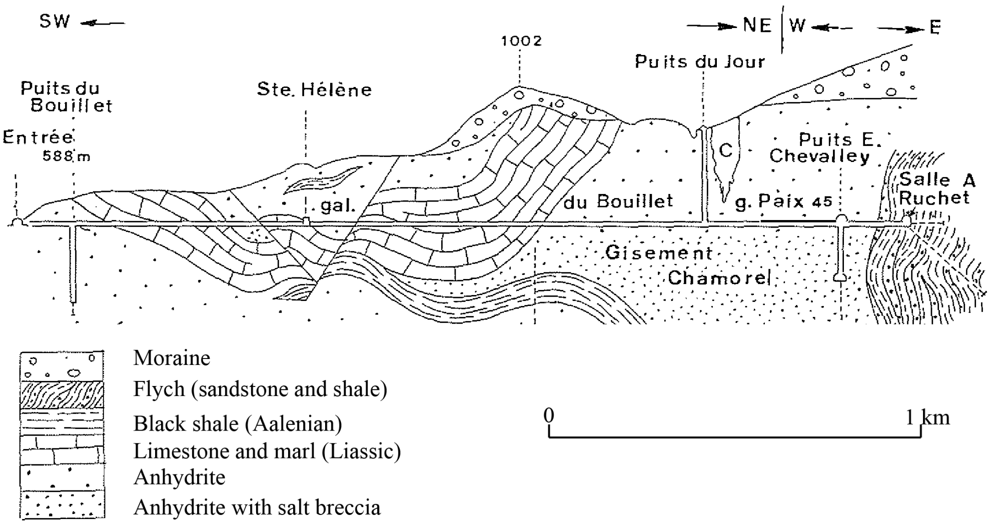


Figure 25 : General cross section through the mine area (adapted from Badoux, 1982).

This complexity of the regional geology is also shown on the tectonic map (Fig. 23) : the main tectonic units, Ultrahelvetic and Penninic are belonging to the distal European continental margin and the Briançonnais sub-plate (Fig. 7).

The salt does not form solid lenses surrounded by anhydrite, but appears as "cement" in a tectonic breccia where it fills the voids (25 % in volume) between the bits of anhydrite, shale and dolomite. The salt is extracted by water injections through borings drilled from inside the old mines. Annual production for the last years : 40'000 to 50'000 tons.

Acccording to Weidmann, 2006, the following evaporite facies are founded in the salt mine galeries :

a- ribbon anhydrite ; b- brecciated anhydrite ; c- grained gypsum with large grain ; d- saccharoidal gypsum ; e- ribbon gypsum ; f- saliferous breccia.

The lithological sketch below is showing a section across a 500 m thick evaporite melange (Fig. 37).

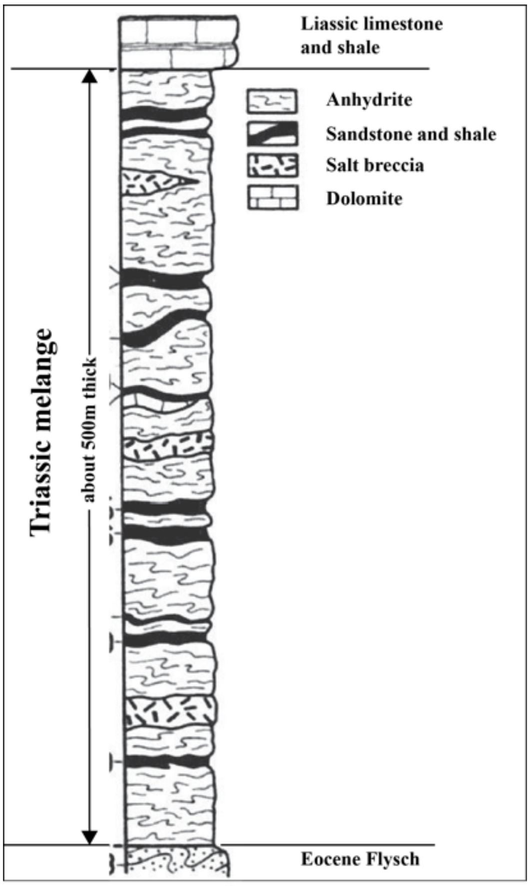


Figure 27 : Lithological sketch across the evaporite (anhydrite –salt breccia) of the salt mine according to Badoux and Weidmann, 1964

Due to the highly complicate tectonic processes, it is not possible to give a precise depositional model (Angeloz, 2014), but with this salt deposit type, now as cement of an anhydrite breccia with strong diagenetic changes followed by a low metamorphism influence, it is interesting to note the appearance of new minerals.

4.2 – Mineralogy and sulfur isotopes (Nicolas Meisser, Figs. 28 to 30).

Fine studies of mineralogical assemblages in the Triassic evaporitic facies show a rich and complex mineral paragenesis (Meisser & Ansermet, 1993). Most of rare minerals are related to alpine low grade metamorphism event or neoformation after mining activities. Sulfur isotope study shows clear genetical trends (Meisser, 2012). One can definite eight different paragenesis :

1. Primary evaporitic minerals, often completely recrystallized during diagenesis and alpine tectonic (halite, anhydrite, massive and platy crystallized gypsum, dolomite, calcite, celestine, barite, pyrite, quartz, native sulphur, sodium carbonates). Sulfur isotopes data for Ultrahelvetic anhydrite have value of +13.1‰, and for Penninic anhydrite, up to +16.7‰. These values are in accordance with oceanic values of this period, but this notable variation have to been studied according paleogeographical and/or age aspects.

2. Late stage alpine veins (< 10 m.y.) crosscutting dolomite, sandstones and black shale with epithermal mineralisations (calcite, pink anhydrite, gemmy gypsum, magnesite, Fe-dolomite, strontianite, celestine, Ba-celestine, native sulfur, chalcopyrite, sphalerite, galena, quartz, hematite, albite, etc.). Sulfur isotopes data of celestine associated with sulfides have high value (+20.2‰ to +25.6‰) and sulfides with lower values (+11.5‰ to +14.5‰). This discrepancy is interpreted as epithermal partial bacterial reduction of Triassic evaporitic sulfate into sulfides species and precipitation as galena and sphalerite. Residual ^{32}S enriched-sulfate precipitate as celestine.
   Large gemmy gypsum crystals embedded in clay, mostly discovered in 1790 and 1817, are world-wide widespread in old mineralogical collections. Most of them are considered as crystallographical morphological types for gypsum (Soret, 1817 ; Dufrénoy, 1848, Meisser, 2014).

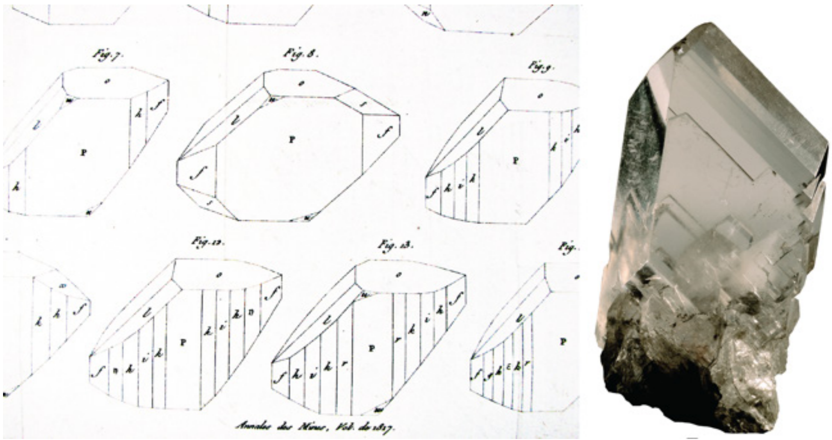


Figure 28 left : Soret (1817) Gypsum plate ; right, Gypsum cristal (paragenesis 2)

3. Quaternary-aged alteration of former mineral assemblages. Mostly dissolution of halite, sulfates and carbonates, massive hydratation of anhydrite into gypsum and clay mineral formation.
4. Post-mining (< 300 years) neoformation or exudations (Fig. 40) of partially water-soluble caliche and efflorescences from evaporites or black shales (gypsum, aragonite, mirabilite, thenardite, epsomite, nahcolite, trona, thermonatrite, natron, eugsterite, hydroglauberite, gaylussite, hydromagnesite, etc.).
   The local abundance of sodium carbonates- bearing mineral species as exudates on anhydrite is interpreted as typical influence of continental ± lacustrine brine. Medium sulfur isotopes data of soluble sodium and magnesium sulfates mirabilite (+ 9.5‰) and epsomite (+11.2‰) co-crystallized with these alkaline carbonates corroborate this genetical hypothesis.
5. Post-mining (< 300 years) neoformation by oxidation of primary iron and copper sulfides dispersed in black shales or epithermal alpine veins (jarosite, natrojarosite, metasideronatrite, tamarugite, melanterite, paratacamite, atacamite, botallackite and several new mineral species under investigation).
6. Sub-actual (< 200 years) alteration of anthropogenic metallic objects or wastes (chaconatronite, posnjakite, devilline, cuprite, simonkolleite, salmiac, etc.).
7. Actual reduction of gypsum by thiobacillum sp. into native sulfur and calcite.
8. Actual crystallization of prismatic crystal of gypsum or cubic halite in underground brine reservoirs (Fig. 39).

Acknowledgements

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