

Don't touch those dials!

How microbes hardwired Earth for a post-human world

Paul G. Falkowski

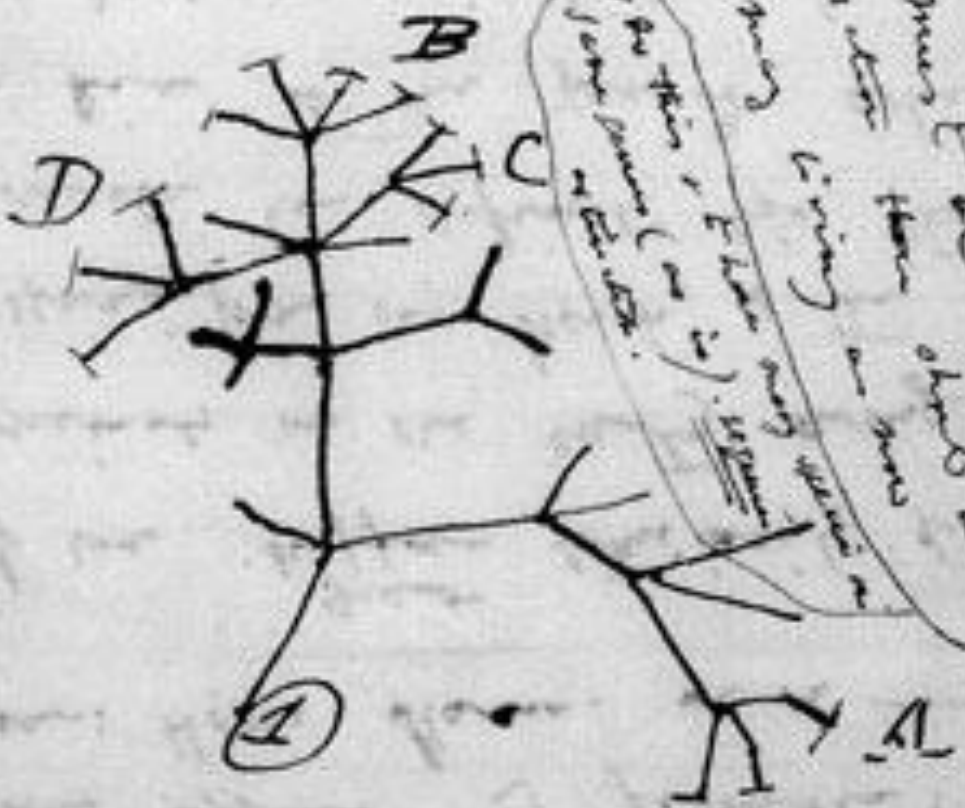
Environmental Biophysics and Molecular Ecology Program

Dept. Of Earth and Planetary Sciences

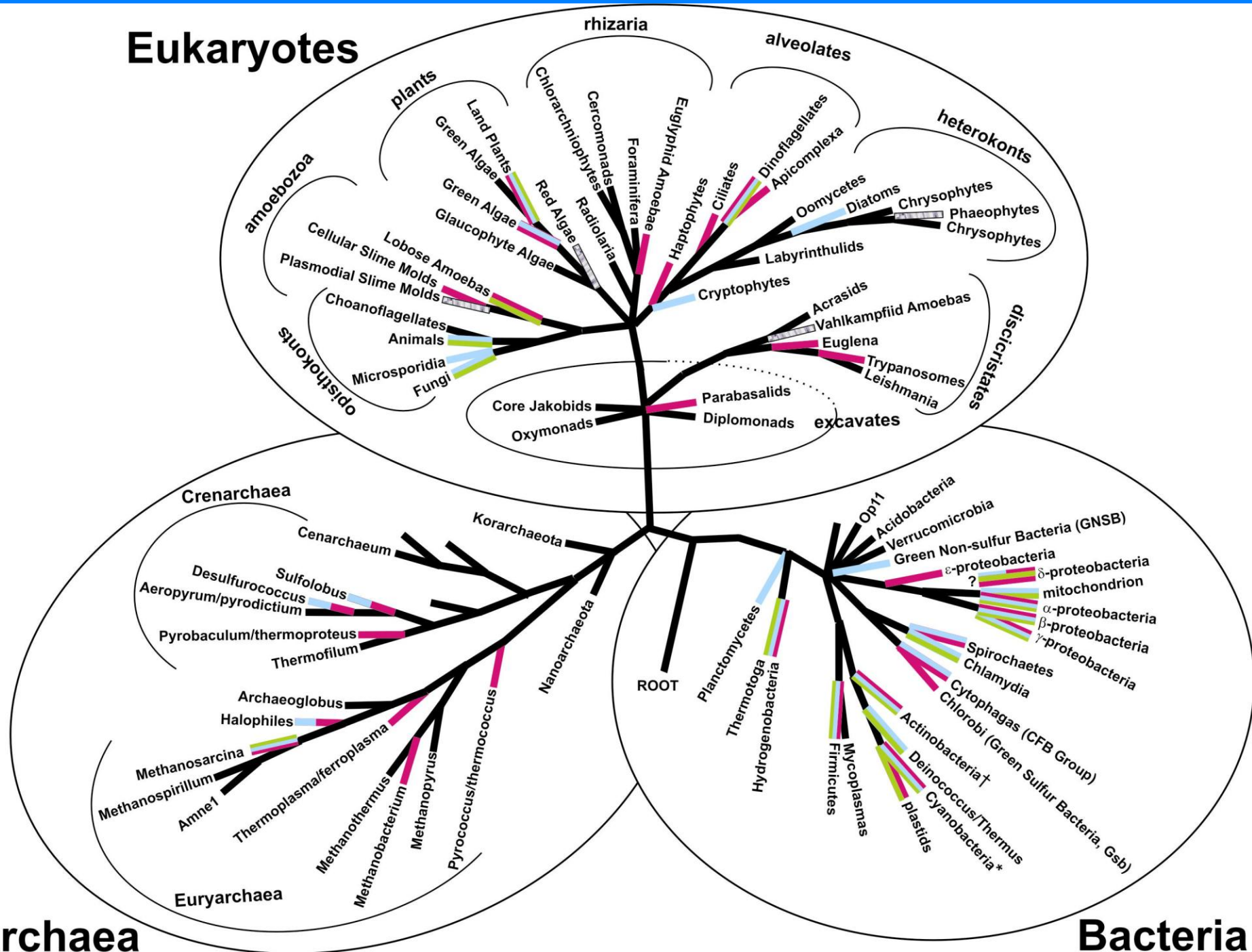
Institute of Marine and Coastal Science

Rutgers University, New Brunswick, NJ

I think

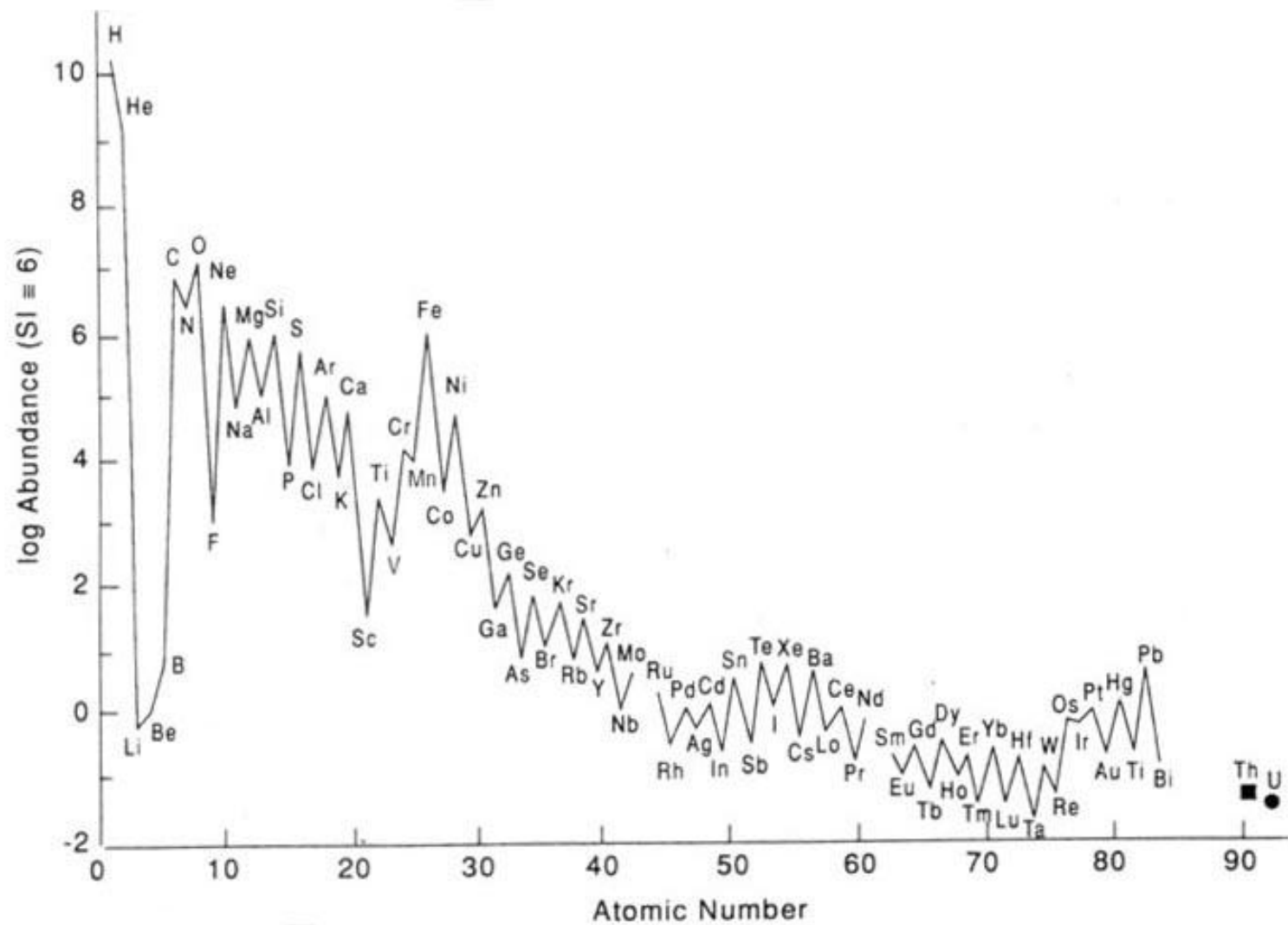


Eukaryotes



Archaea

Bacteria



The origin of life is the invention of
non-equilibrium redox chemistry that
involves five of the
The “Big Six”

H, C, N, O, P and S

**And at least 54 other “trace
elements”**

Life is Electric

- All organisms derive energy for growth and maintenance by moving electrons from a substrate to a product.
- All substrates and products must ultimately be cycled.
- Biological processes are paired (e.g., photosynthesis and respiration)

Microbes are like lawyers –they cannot exist alone

The electron “marketplace”

Maintaining life on a planet
requires recycling of electrons

What were the sources and sinks
of electrons in the Archean and
what are they today?

**The major sources of electrons
during the Archean were**

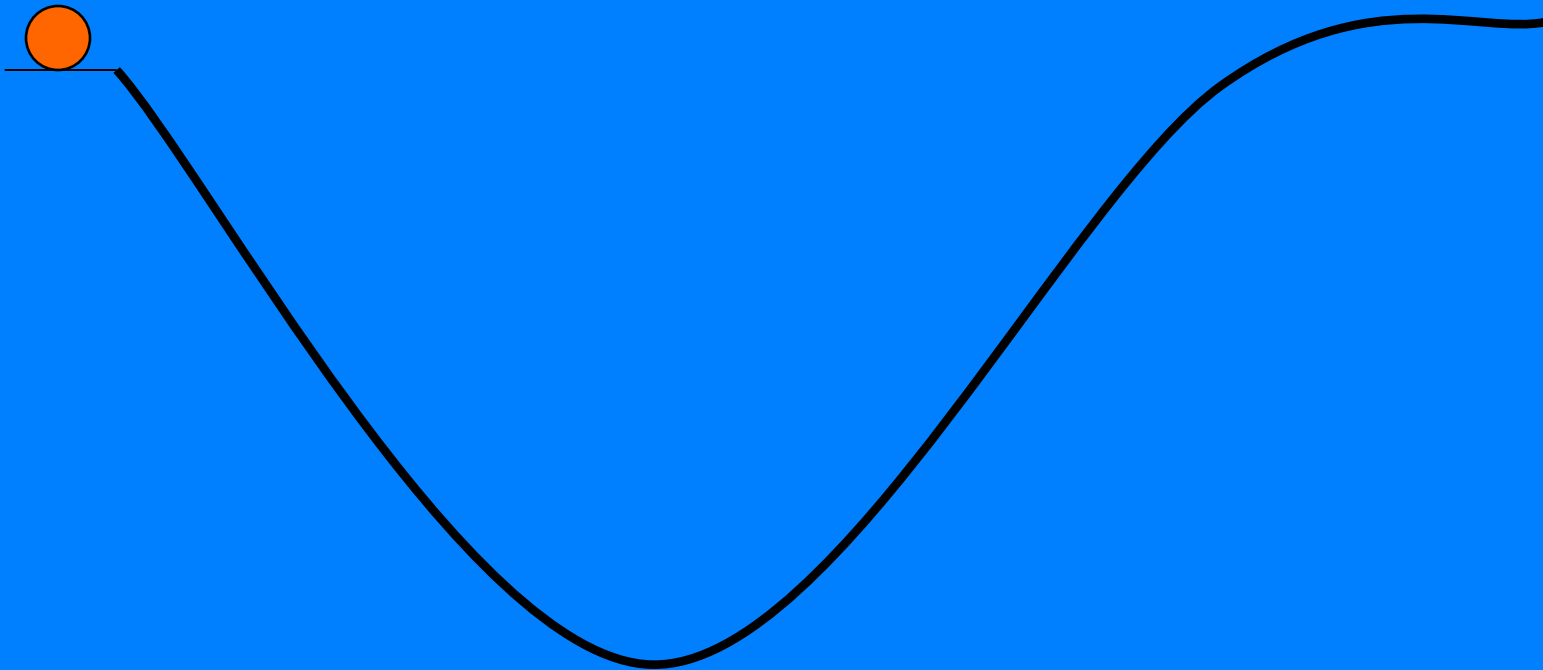
H_2S , Fe(II) , and H_2

**The major source of electrons
today is**

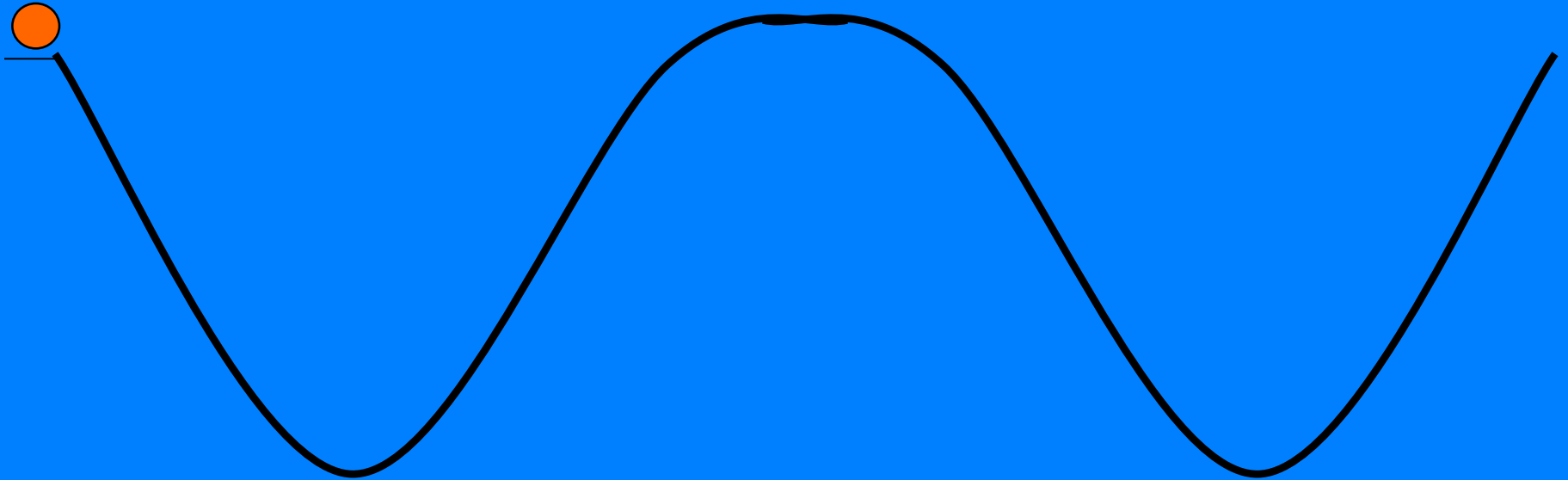
LIQUID WATER

(H₂O)

The “Ball in the Bowl” metaphor for the first (R&D) half of Earth’s History



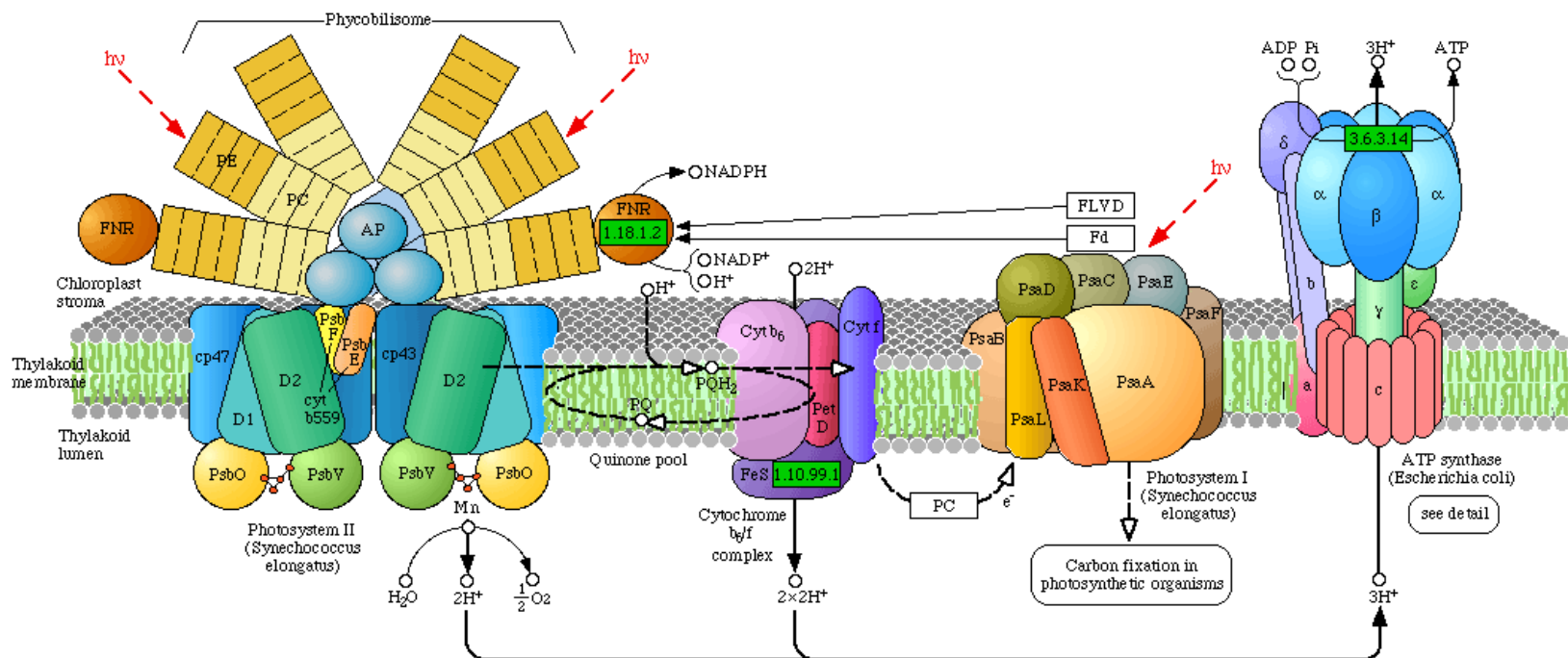
**The “Big Flip” into the second half of
Earth’s history – why did Earth become
oxidized anyway?**



The evolution of nannomachines

The fundamental problem in origins
of life - evolution of energy
transduction before information?
Or vice versa?

PHOTOSYNTHESIS



Photosystem II

D1	D2	cp43	cp47	cyt b559
PsbA	PsbD	PsbC	PsbE	PsbF

PsbL	PsbJ	PsbK	PsbM	PsbN	PsbH	PsbT	PsbI
PsbO	PsbP	PsbU	PsbV	PsbW	PsbX	PsbY	PsbZ

Photosystem I

PsaA	PsaB	PsaC	PsaD	PsaE	PsaF	PsaH	PsaI
PsaJ	PsaK	PsaL	PsaM	PsaN	PsaX		

Cytochrome b_6/f complex

PetB	PetD	PetA	PetC	PetL	PetM	PetN	PetG	PetE	PetF	PetH
------	------	------	------	------	------	------	------	------	------	------

Allophycocyanin (AP)

ApcA	ApcB	ApcC	ApcD	ApcE	ApcF
------	------	------	------	------	------

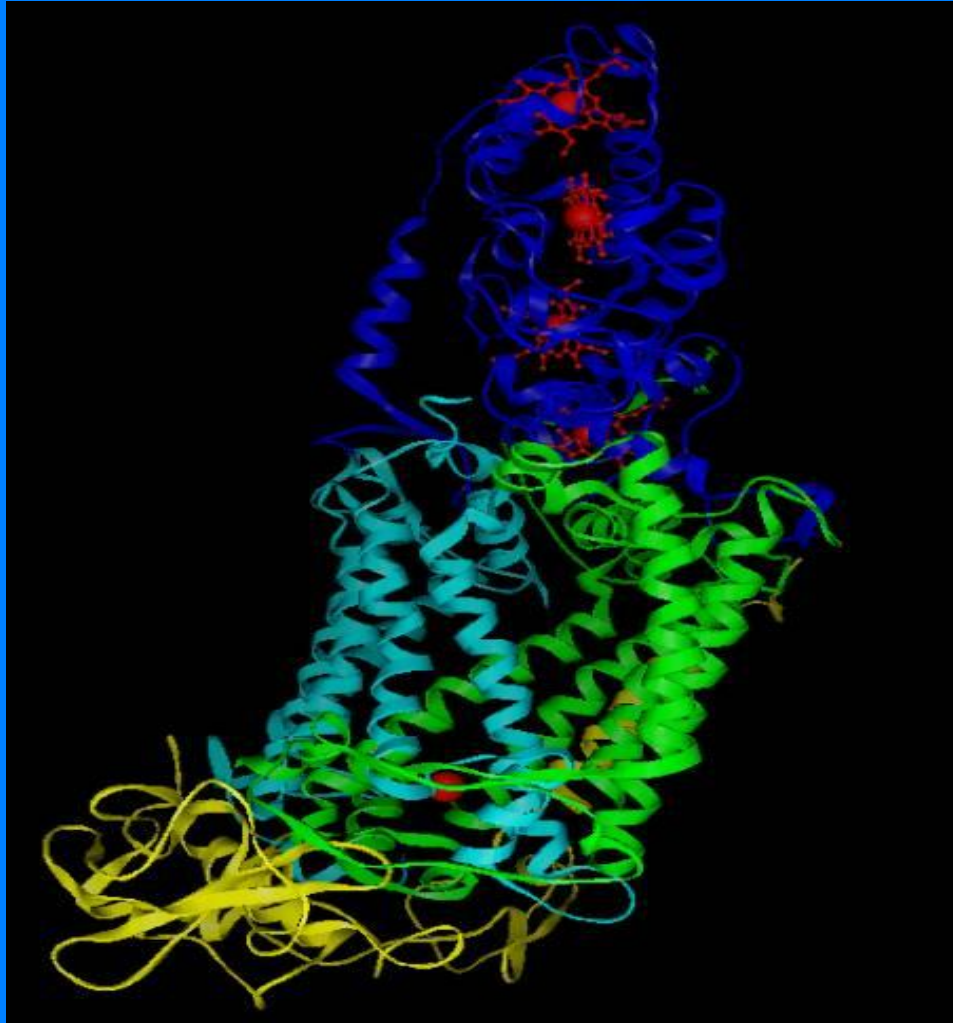
Phycocyanine (PC)

CpcA	CpcB	CpcC	CpcD	CpcE	CpcF	CpcG
------	------	------	------	------	------	------

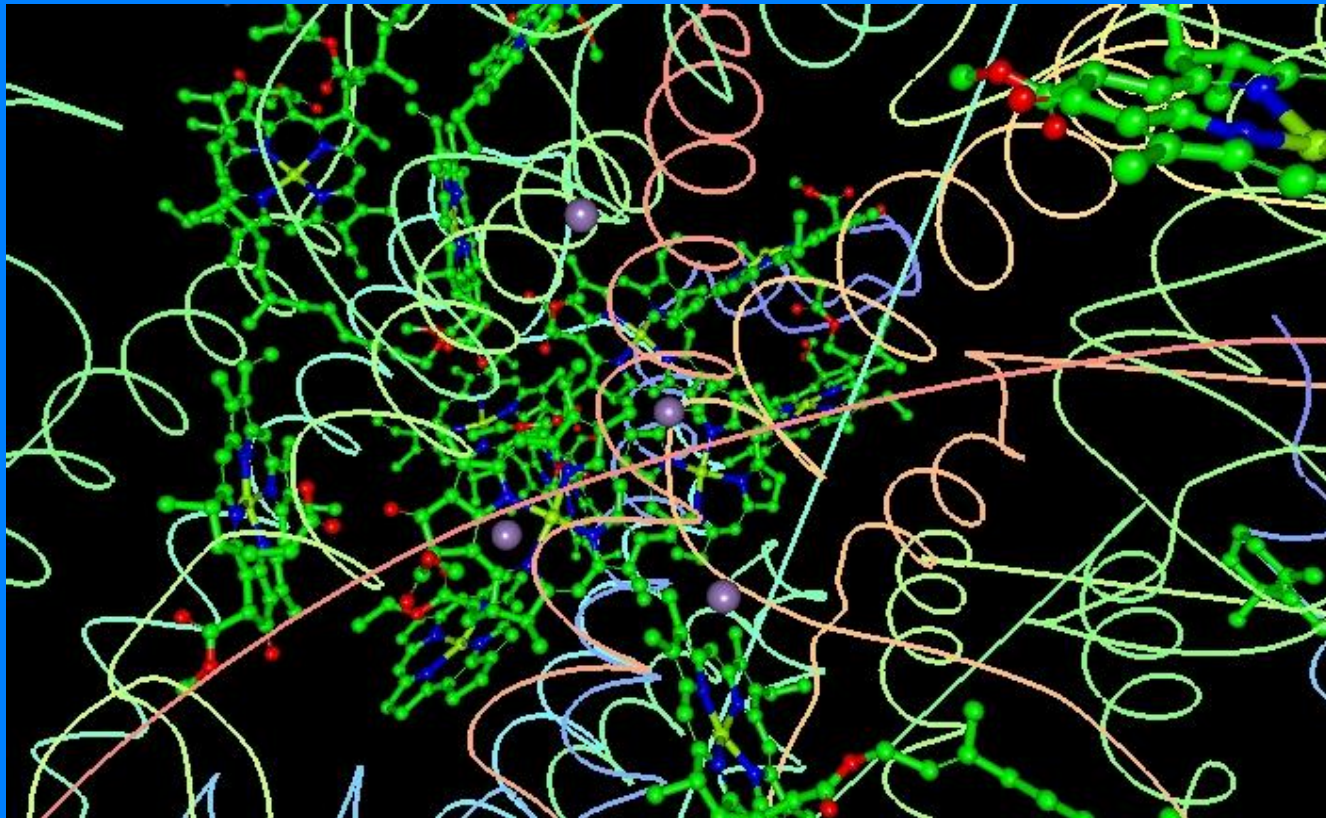
Phycocerythrin (PE)

PecA	PecB	PecC	PecE	PecF
------	------	------	------	------

PSII type Reaction Center



The Mn cluster in PS II

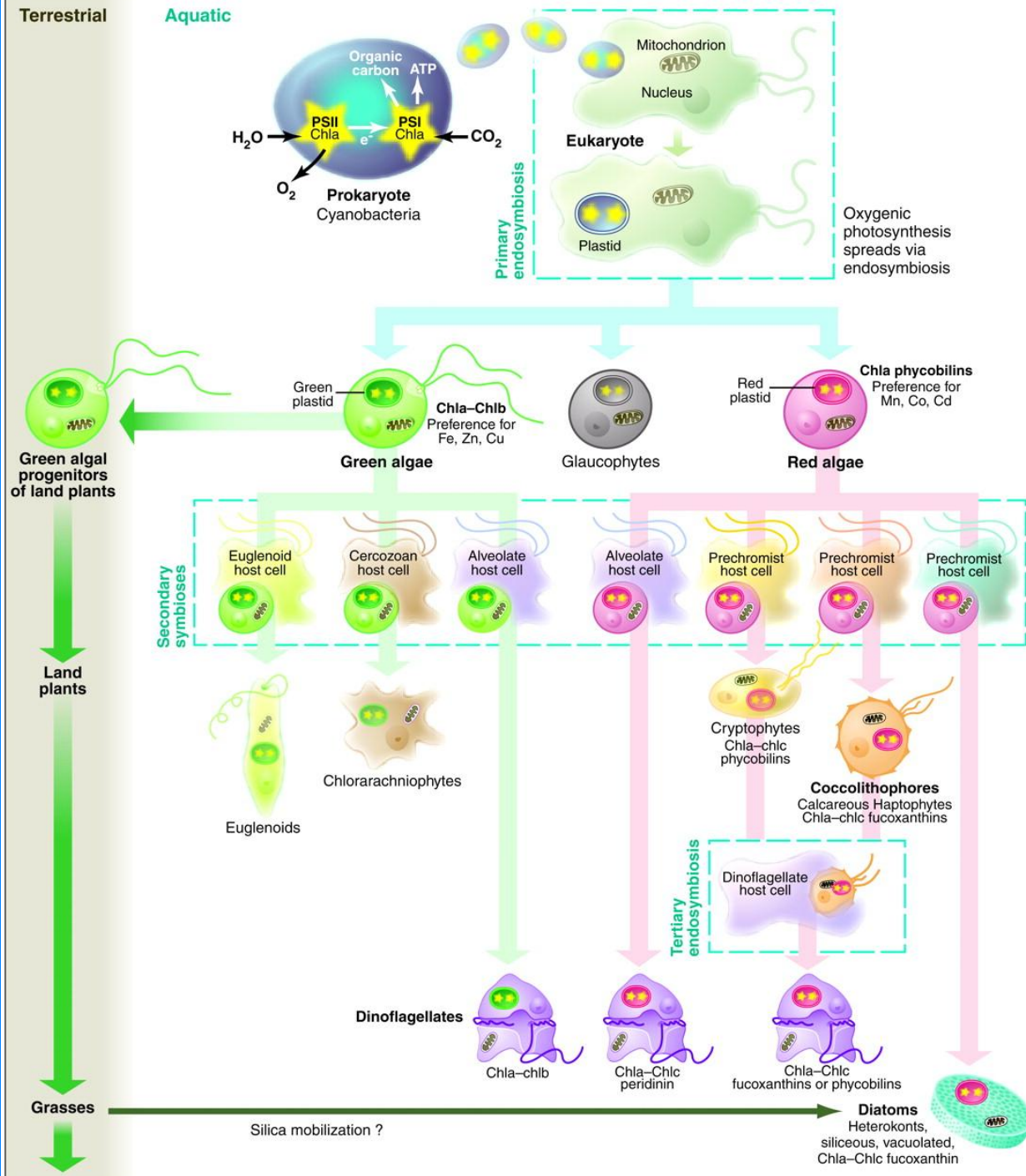


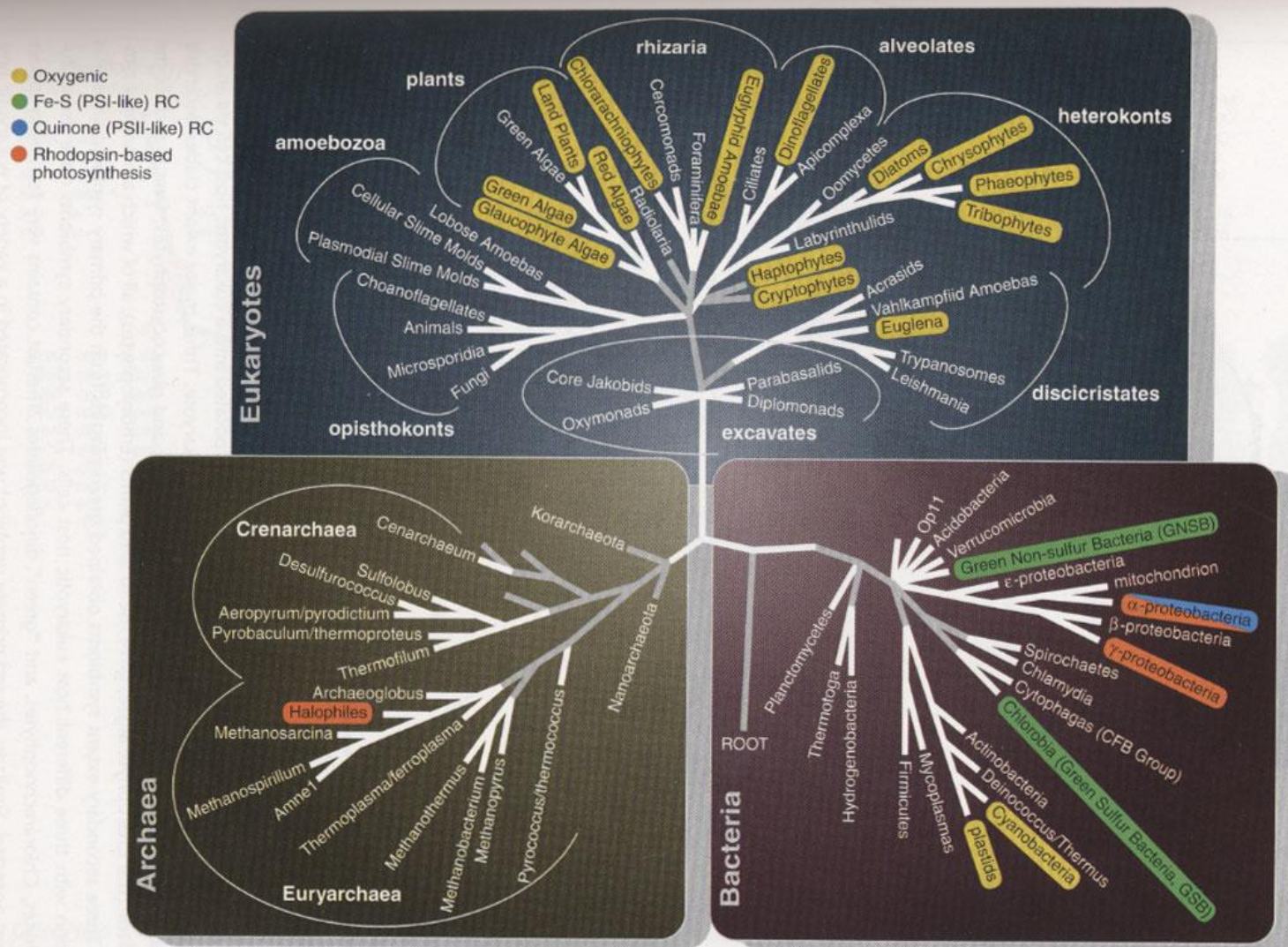
Nature's insurance policy

Spread the risk

Terrestrial

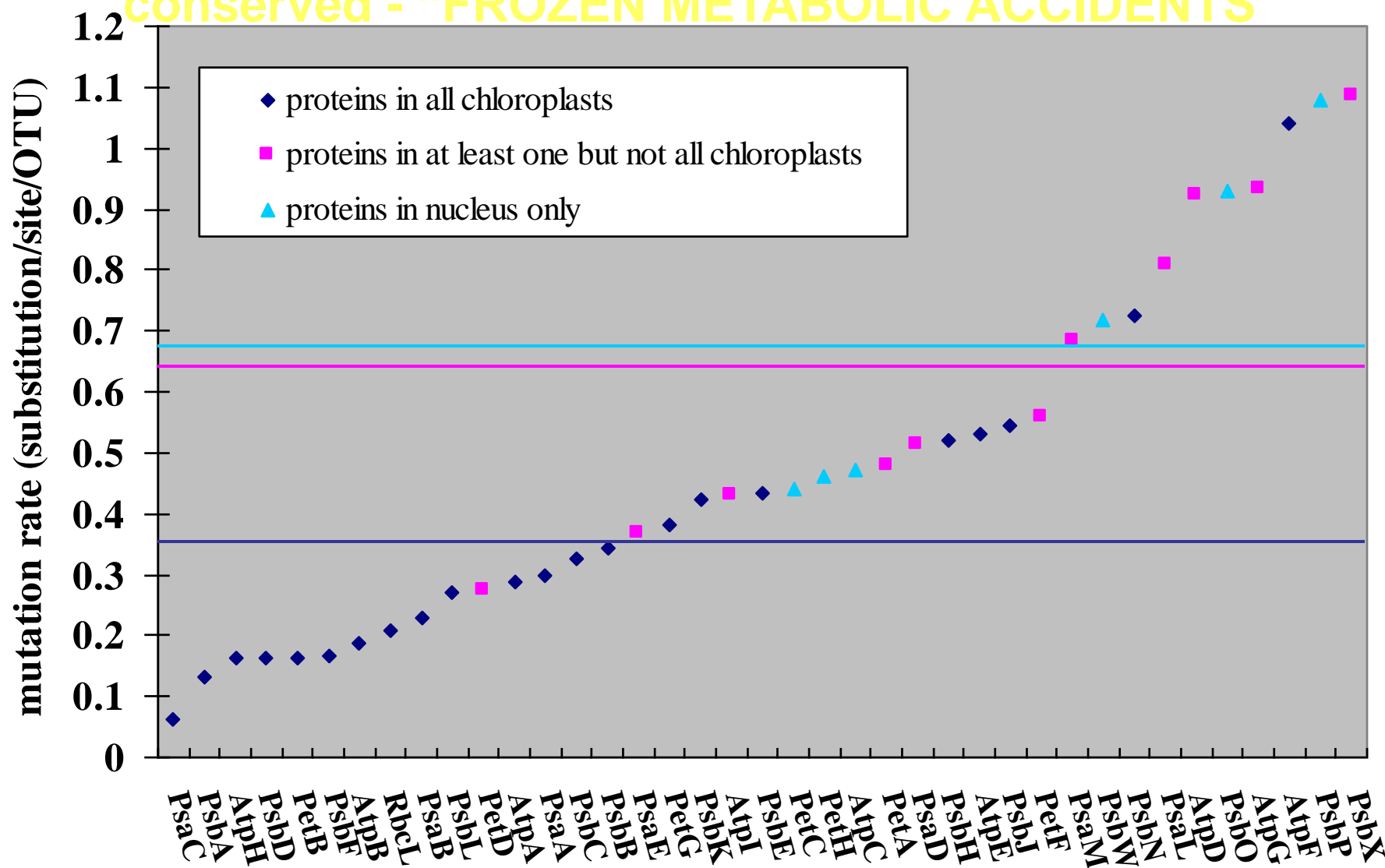
Aquatic

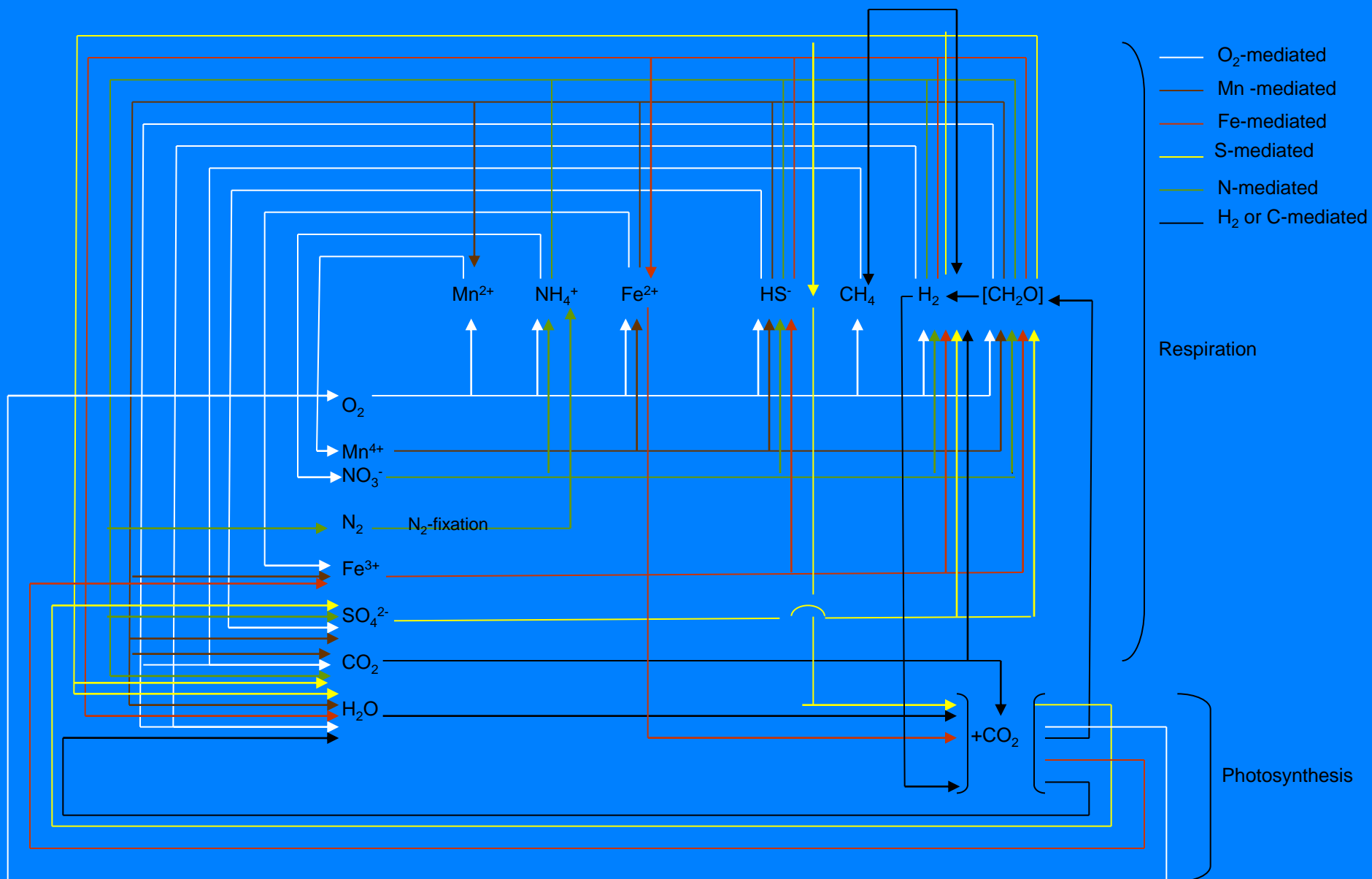




Color Plate 1: A phylogenetic tree of life constructed from ribosomal DNA and other traits showing the evolutionary patterns of major clades of known prokaryotic and eukaryotic taxa and the distribution of photosynthetic metabolic pathways among them. (This tree was modified from a figure kindly provided by Sandie Baldauf.)

PS genes retained in chloroplasts are very highly conserved - "FROZEN METABOLIC ACCIDENTS"





Tube map

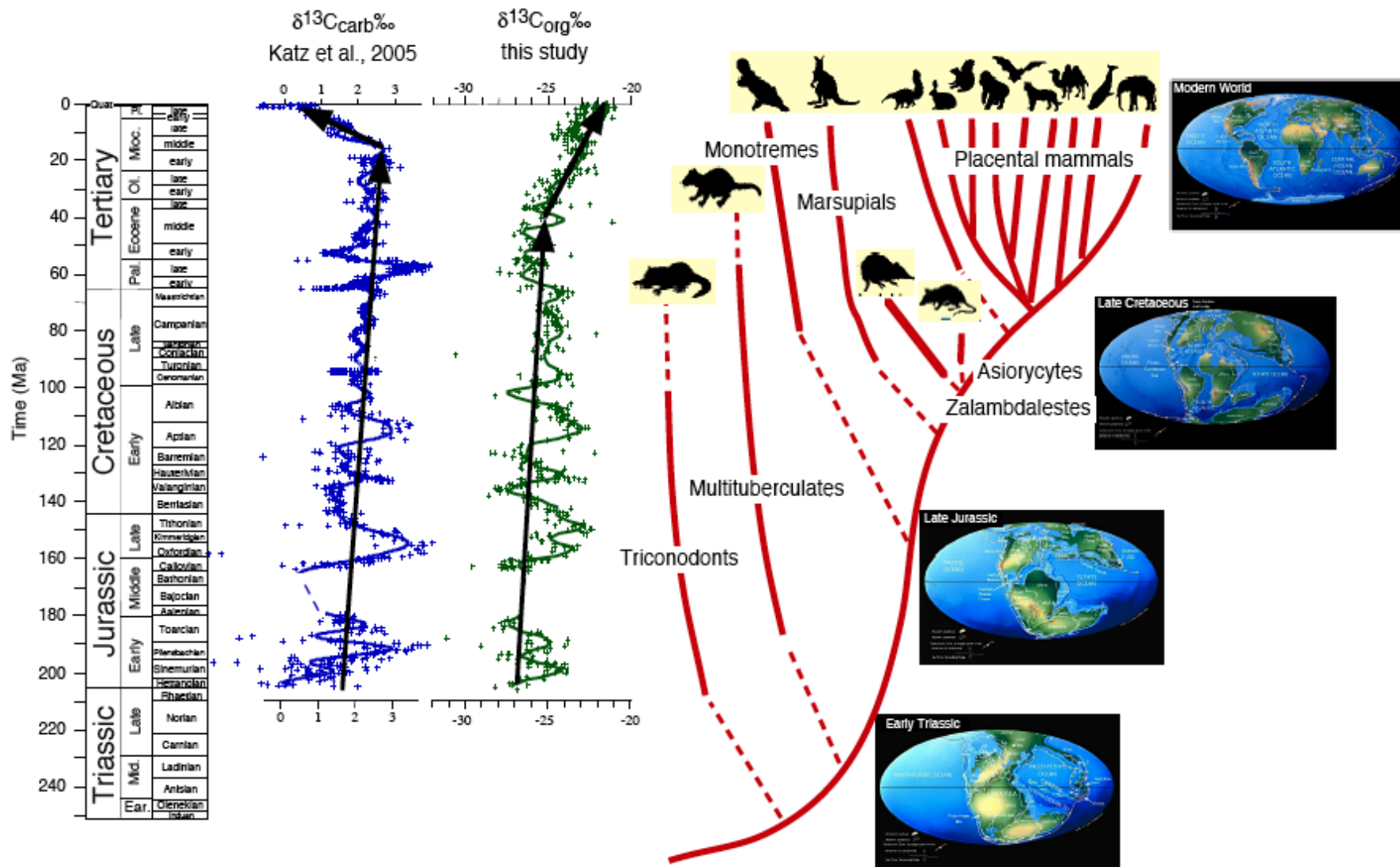


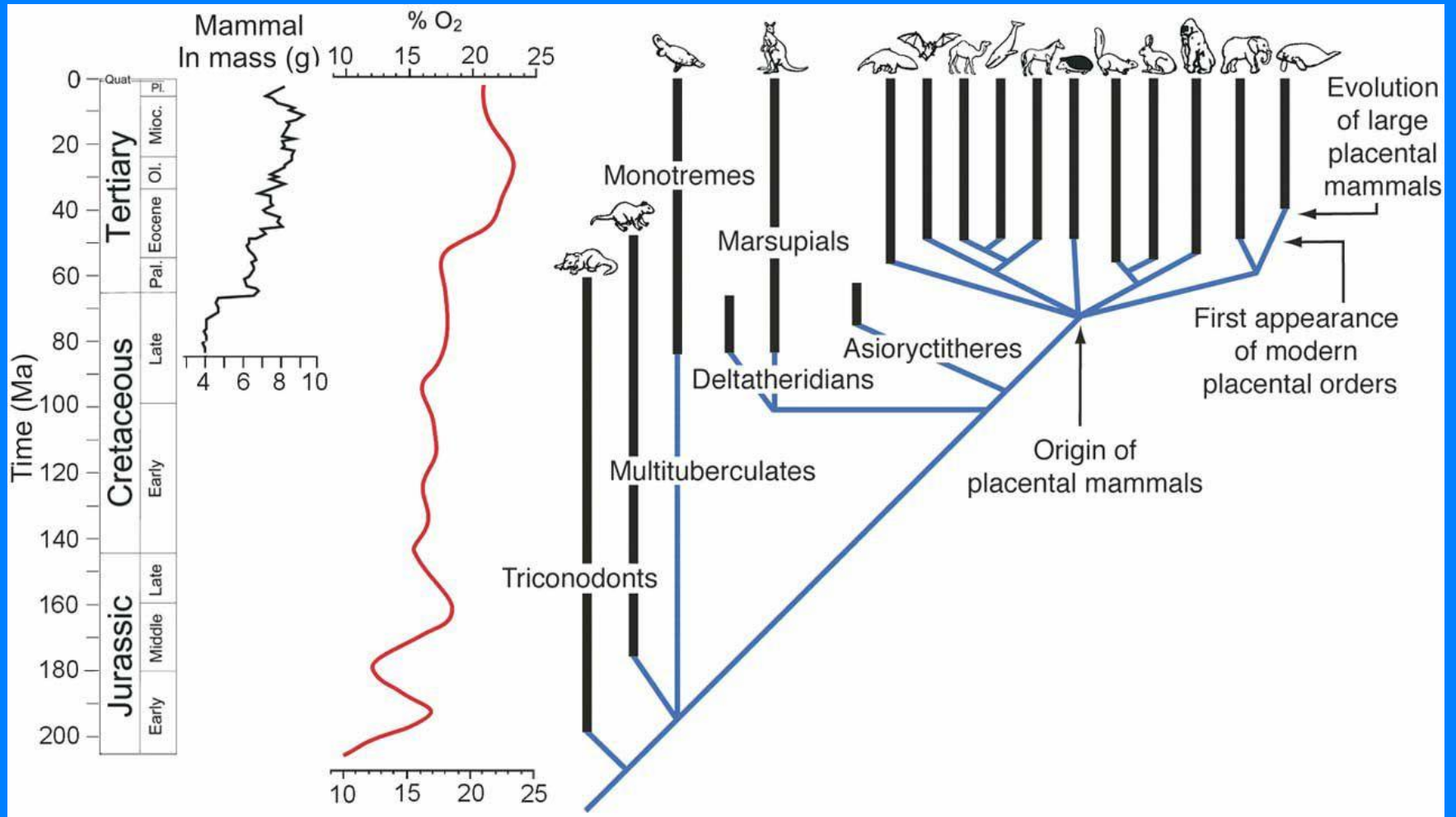
- Bakerloo
- Central
- Circle
- District
- East London
- Hammersmith & City
- Jubilee
- Metropolitan
- Northern
- Piccadilly
- Victoria
- Waterloo & City
- London Overground
- DLR

- Interchange stations
- Step-free access from the platform to the street
- Connections with National Rail
- Check before you travel. See index below
- Connections with riverboat services
- Connection with Tramlink
- Location of Airport
- Interchange with National Rail services to airport
- Replacement bus service
- Bicycle parking
- Car parks
- Toilets on site/nearby
- Travel Information Centres

- D Station in Zone D
- C Station in Zone C
- B Station in Zone B
- A Station in Zone A
- Station in Zone A and Zone B
- Station in Zone B
- Station in Zone C
- Station in Zone D
- Station in both zones
- Station in Zone 2
- Station in both zones
- Station in Zone 1

1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25	26	27
28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54
55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81
82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99
100	101	102	103	104	105	106	107	108
109	110	111	112	113	114	115	116	117
118	119	120	121	122	123	124	125	126
127	128	129	130	131	132	133	134	135
136	137	138	139	140	141	142	143	144
145	146	147	148	149	150	151	152	153
154	155	156	157	158	159	160	161	162
163	164	165	166	167	168	169	170	171
172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189
190	191	192	193	194	195	196	197	198
199	200	201	202	203	204	205	206	207
208	209	210	211	212	213	214	215	216
217	218	219	220	221	222	223	224	225
226	227	228	229	230	231	232	233	234
235	236	237	238	239	240	241	242	243
244	245	246	247	248	249	250	251	252
253	254	255	256	257	258	259	260	261
262	263	264	265	266	267	268	269	270
271	272	273	274	275	276	277	278	279
280	281	282	283	284	285	286	287	288
289	290	291	292	293	294	295	296	297
298	299	300	301	302	303	304	305	306
307	308	309	310	311	312	313	314	315
316	317	318	319	320	321	322	323	324
325	326	327	328	329	330	331	332	333
334	335	336	337	338	339	340	341	342
343	344	345	346	347	348	349	350	351
352	353	354	355	356	357	358	359	360
361	362	363	364	365	366	367	368	369
370	371	372	373	374	375	376	377	378
379	380	381	382	383	384	385	386	387
388	389	390	391	392	393	394	395	396
397	398	399	400	401	402	403	404	405
406	407	408	409	410	411	412	413	414
415	416	417	418	419	420	421	422	423
424	425	426	427	428	429	430	431	432
433	434	435	436	437	438	439	440	441
442	443	444	445	446	447	448	449	450
451	452	453	454	455	456	457	458	459
460	461	462	463	464	465	466	467	468
469	470	471	472	473	474	475	476	477
478	479	480	481	482	483	484	485	486
487	488	489	490	491	492	493	494	495
496	497	498	499	500	501	502	503	504
505	506	507	508	509	510	511	512	513
514	515	516	517	518	519	520	521	522
523	524	525	526	527	528	529	530	531
532	533	534	535	536	537	538	539	540
541	542	543	544	545	546	547	548	549
550	551	552	553	554	555	556	557	558
559	560	561	562	563	564	565	566	567
568	569	570	571	572	573	574	575	576
577	578	579	580	581	582	583	584	585
586	587	588	589	590	591	592	593	594
595	596	597	598	599	600	601	602	603
604	605	606	607	608	609	610	611	612
613	614	615	616	617	618	619	620	621
622	623	624	625	626	627	628	629	630
631	632	633	634	635	636	637	638	639
640	641	642	643	644	645	646	647	648
649	650	651	652	653	654	655	656	657
658	659	660	661	662	663	664	665	666
667	668	669	670	671	672	673	674	675
676	677	678	679	680	681	682	683	684
685	686	687	688	689	690	691	692	693
694	695	696	697	698	699	700	701	702
703	704	705	706	707	708	709	710	711
712	713	714	715	716	717	718	719	720
721	722	723	724	725	726	727	728	729
730	731	732	733	734	735	736	737	738
739	740	741	742	743	744	745	746	747
748	749	750	751	752	753	754	755	756
757	758	759	760	761	762	763	764	765
766	767	768	769	770	771	772	773	774
775	776	777	778	779	780	781	782	783
784	785	786	787	788	789	790	791	792
793	794	795	796	797	798	799	800	801
802	803	804	805	806	807	808	809	810
811	812	813	814	815	816	817	818	819
820	821	822	823	824	825	826	827	828
829	830	831	832	833	834	835	836	837
838	839	840	841	842	843	844	845	846
847	848	849	850	851	852	853	854	855
856	857	858	859	860	861	862	863	864
865	866	867	868	869	870	871	872	873
874	875	876	877	878	879	880	881	882
883	884	885	886	887	888	889	890	891
892	893	894	895	896	897	898	899	900
901	902	903	904	905	906	907	908	909
910	911	912	913	914	915	916	917	918
919	920	921	922	923	924	925	926	927
928	929	930	931	932	933	934	935	936
937	938	939	940	941	942	943	944	945
946	947	948	949	950	951	952	953	954
955	956	957	958	959	960	961	962	963
964	965	966	967	968	969	970	971	972
973	974	975	976	977	978	979	980	981
982	983	984	985	986	987	988	989	990
991	992	993	994	995	996	997	998	999
1000	1001	1002	1003	1004	1005	1006	1007	1008
1009	1010	1011	1012	1013	1014	1015	1016	1017
1018	1019	1020	1021	1022	1023	1024	1025	1026
1027	1028	1029	1030	1031	1032	1033	1034	1035
1036	1037	1038	1039	1040	1041	1042	1043	1044
1045	1046	1047	1048	1049	1050	1051	1052	1053
1054	1055	1056	1057	1058	1059	1060	1061	1062
1063	1064	1065	1066	1067	1068	1069	1070	1071
1072	1073	1074	1075	1076	1077	1078	1079	1080
1081	1082	1083	1084	1085	1086	1087	1088	1089
1090	1091	1092	1093	1094	1095	1096	1097	1098
1099	1100	1101	1102	1103	1104	1105	1106	1107
1108	1109	1110	1111	1112	1113	1114	1115	1116
1117	1118	1119	1120	1121	1122	1123	1124	1125
1126	1127	1128	1129	1130	1131	1132	1133	1134
1135	1136	1137	1138	1139	1140	1141	1142	1143
1144	1145	1146	1147	1148	1149	1150	1151	1152
1153	1154	1155	1156	1157	1158	1159	1160	1161
1162	1163	1164	1165	1166	1167	1168	1169	1170
1171	1172	1173	1174	1175	1176	1177	1178	1179
1180	1181	1182	1183	1184	1185	1186	1187	1188
1189	1190	1191	1192	1193	1194	1195	1196	1197
1198	1199	1200	1201	1202	1203	1204	1205	1206
1207	1208	1209	1210	1211	1212	1213	1214	1215
1216	1217	1218	1219	1220	1221	1222	1223	1224
1225	1226	1227	1228	1229	1230	1231	1232	1233
1234	1235	1236	1237	1238	1239	1240	1241	1242
1243	1244	1245	1246	1247	1248	1249	1250	1251
1252	1253	1254	1255	1256	1257	1258	1259	1260
1261	1262	1263	1264	1265	1266	1267	1268	1269
1270	1271	1272	1273	1274	1275	1276	1277	1278
1279	1280	1281	1282	1283	1284	1285	1286	1287
1288	1289	1290	1291	1292	1293	1294	1295	1296
1297	1298	1299	1300	1301	1302	1303	1304	1305
1306	1307	1308	1309	1310	1311	1312	1313	1314
1315	1316	1317	1318	1319	1320	1321	1322	1323
1324	1325	1326	1327	1328	1329	1330	1331	1332





Earth is “hard wired” by microbial metabolism

Effectively, the metabolism of Earth was created over 2 billion years ago - and hasn't changed very much.

Humans are effectively, fragile, inefficient *E. coli* that have learned how to plunder the planet

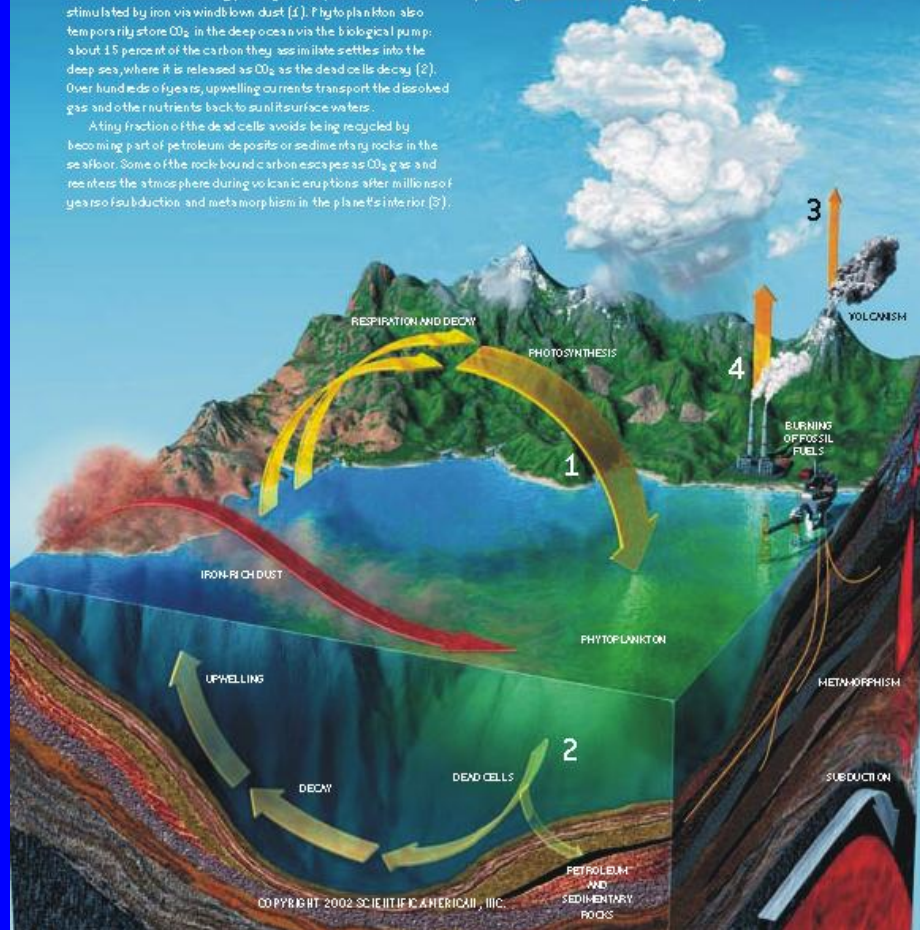
Phytoplankton's Influence on the Global Carbon Cycle

THE EARTH'S CARBON CYCLE can dramatically influence global climate, depending on the relative amounts of heat-trapping carbon dioxide (CO_2) that move into (yellow arrows) and out of (green arrows) the atmosphere and upper ocean, which exchange gases every six years or so. Plantlike organisms called phytoplankton play four critical roles in this cycle. These microscopic ocean dwellers annually incorporate about 50 billion metric tons of carbon into their cells during photosynthesis, which is often stimulated by iron via wind-blown dust (1). Phytoplankton also temporarily store CO_2 in the deep ocean via the biological pump: about 15 percent of the carbon they assimilate settles into the deep sea, where it is released as CO_2 as the dead cells decay (2). Over hundreds of years, upwelling currents transport the dissolved gas and other nutrients back to sunlit surface waters.

A tiny fraction of the dead cells avoids being recycled by becoming part of petroleum deposits or sedimentary rocks in the seafloor. Some of the rock-bound carbon escapes as CO_2 gas and reenters the atmosphere during volcanic eruptions after millions of years of subduction and metamorphism in the planet's interior (3).

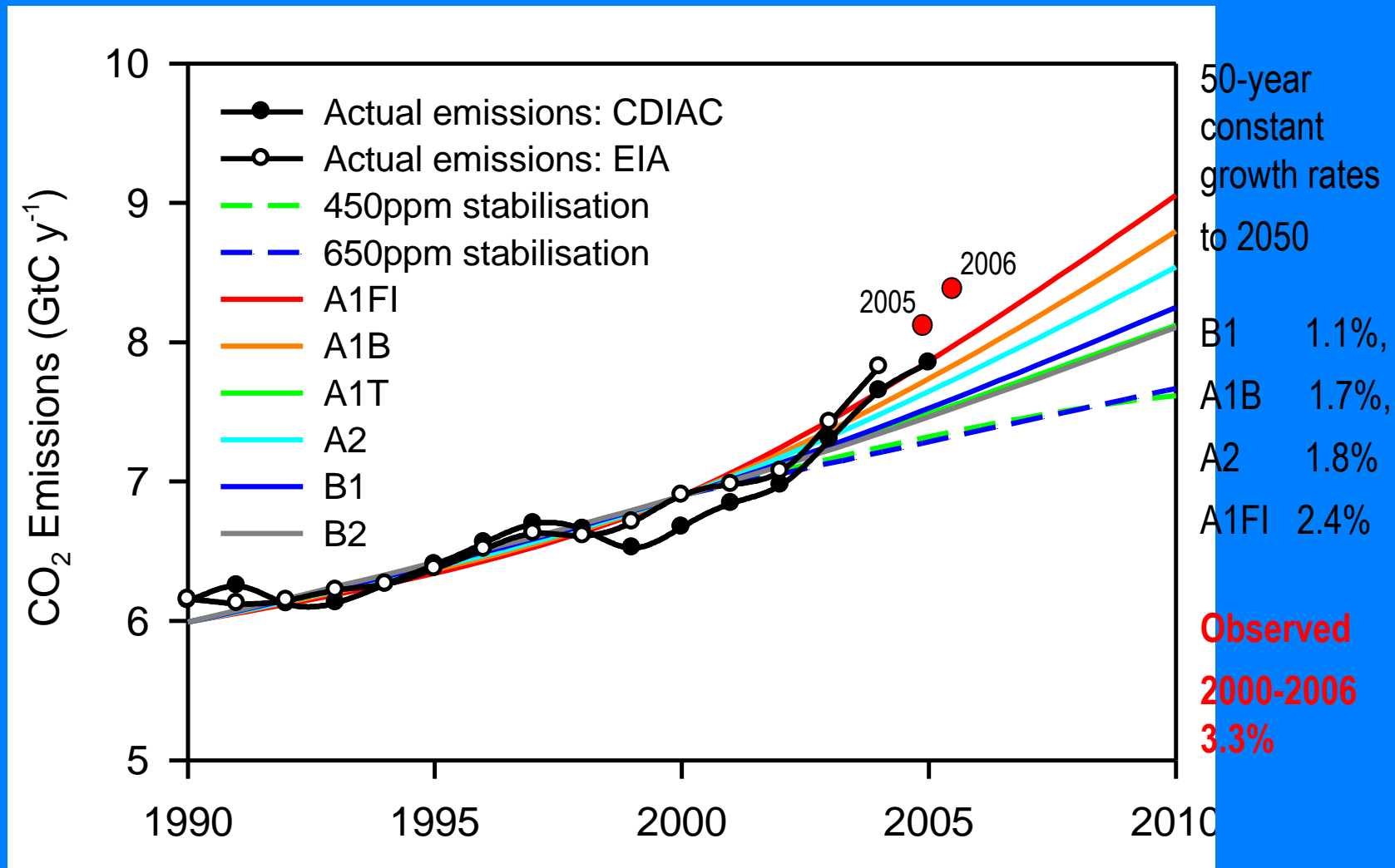
Burning of fossil fuels, in contrast, returns CO_2 to the atmosphere about a million times faster (4). Marine phytoplankton and terrestrial forests cannot naturally incorporate CO_2 quickly enough to mitigate this increase; as a consequence, the global carbon cycle has fallen out of balance, warming the planet. Some people have considered correcting this disparity by fertilizing the oceans with dilute iron solutions to artificially enhance phytoplankton photosynthesis and the biological pump.

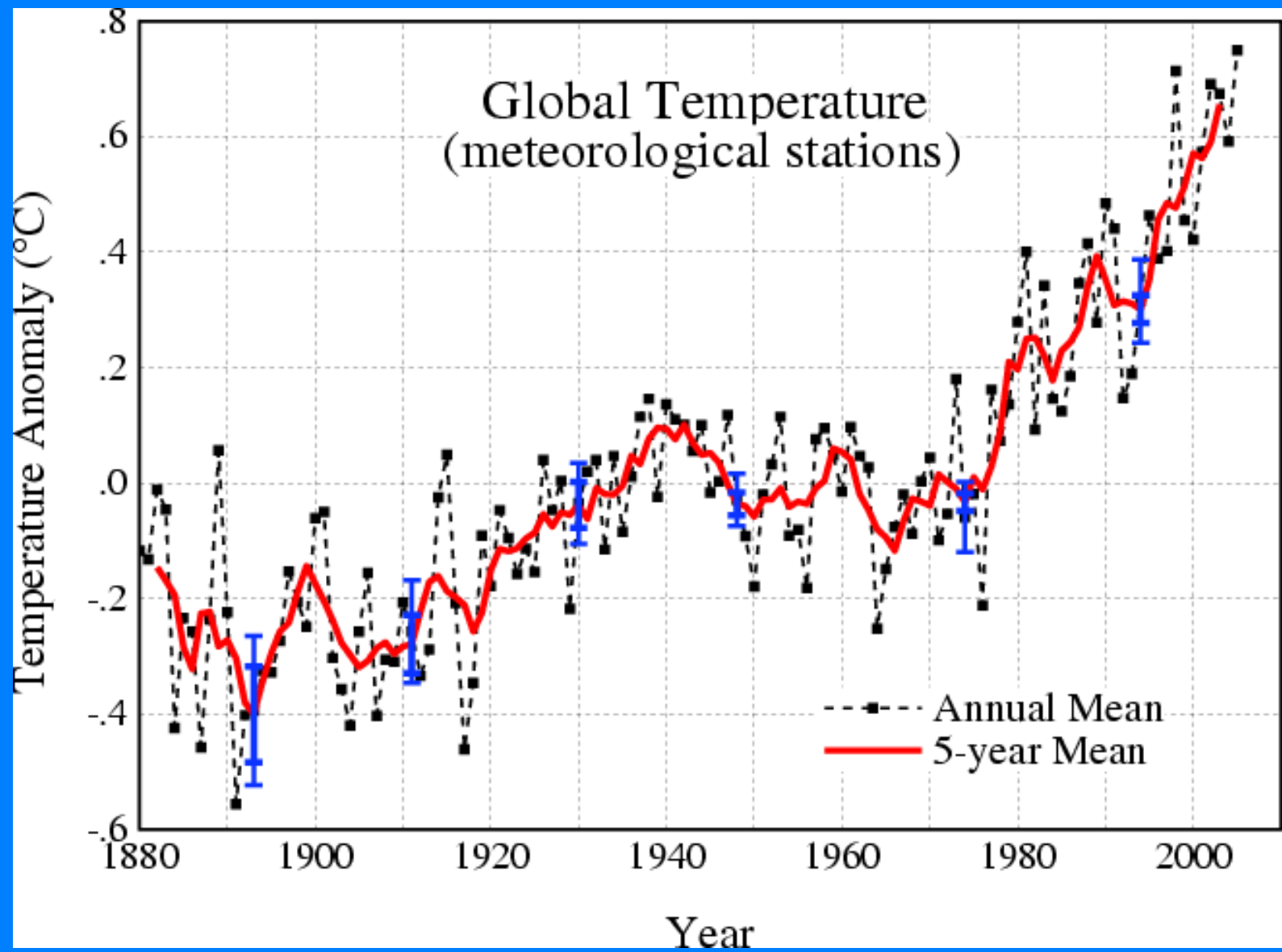
—P.G.F.



Source: Falkowski 2002 Scientific American

Trajectory of Global Fossil Fuel Emissions

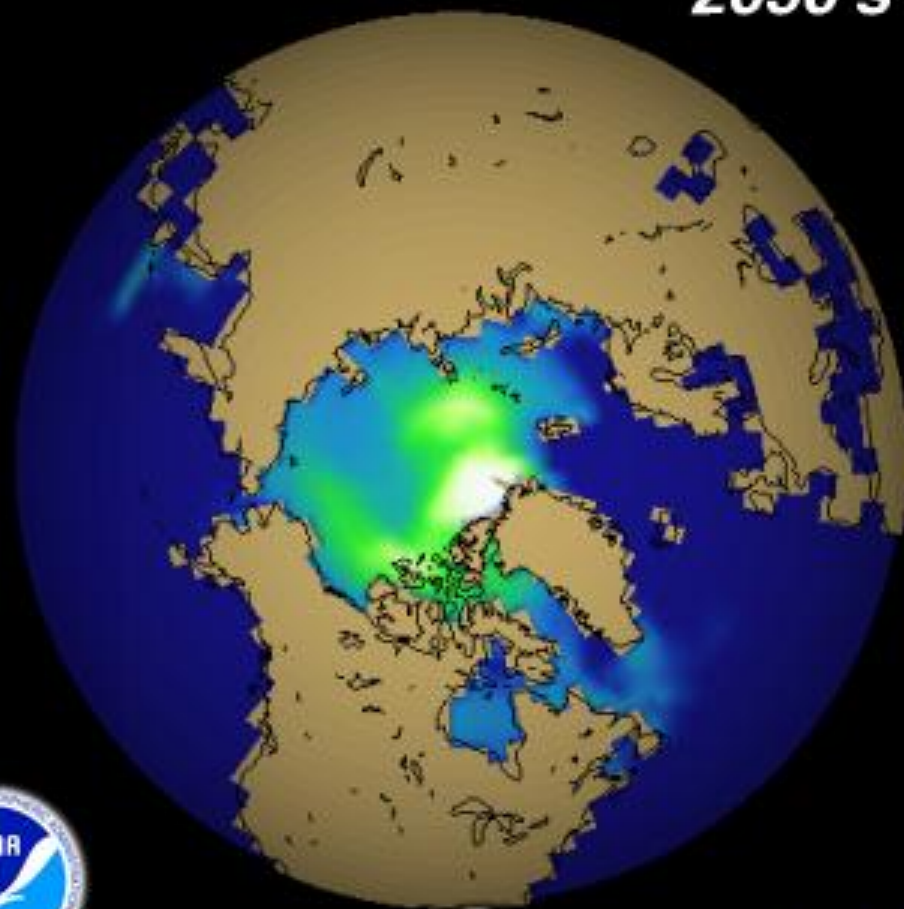
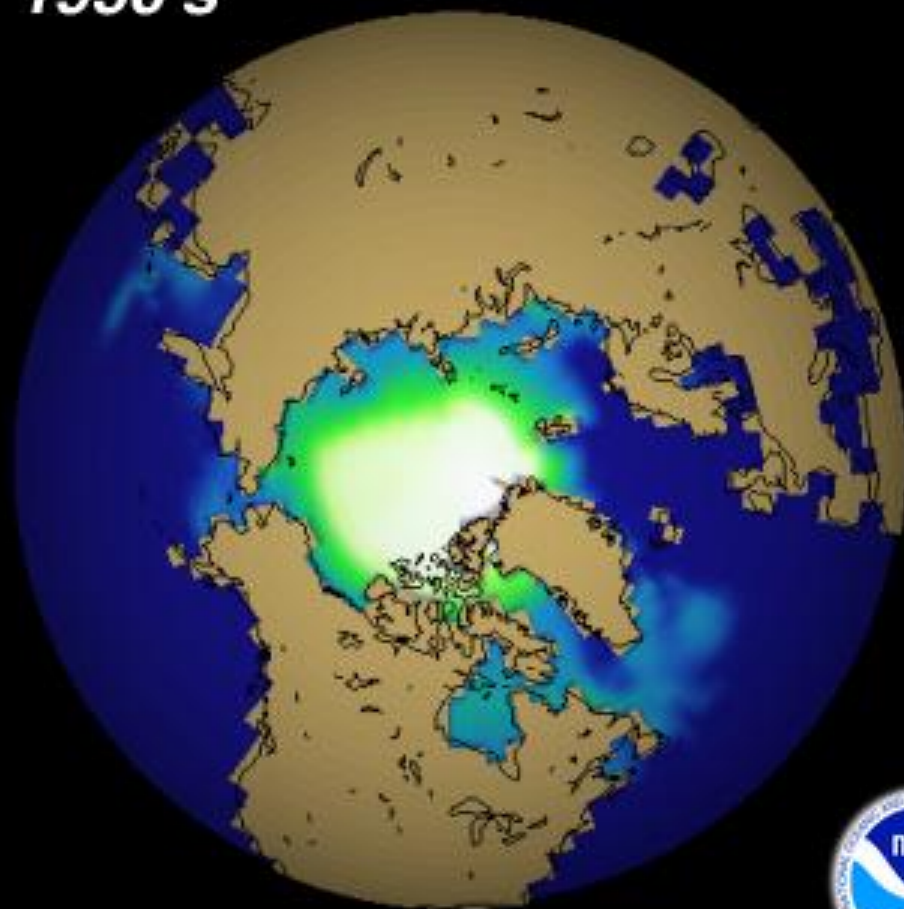




Sea Ice Thickness (10-year average)

1950's

2050's

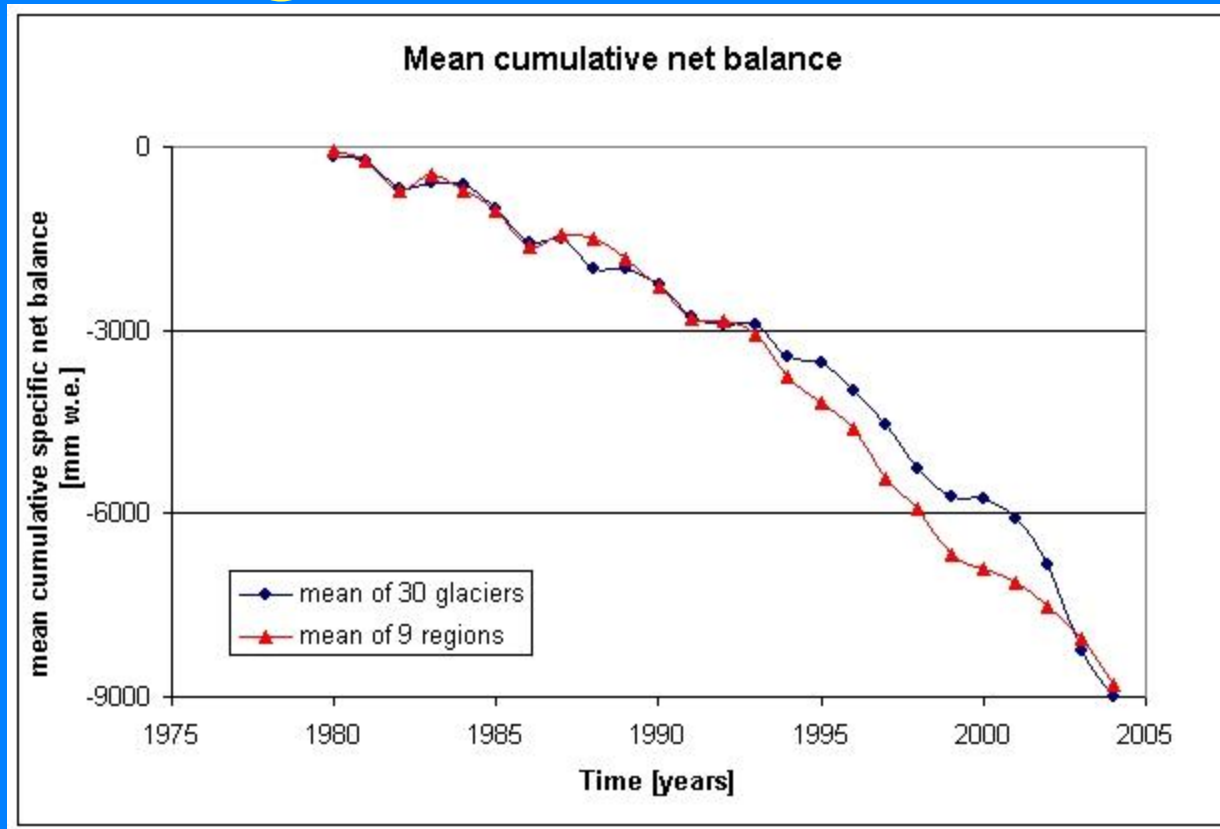


100% of
1955 volume

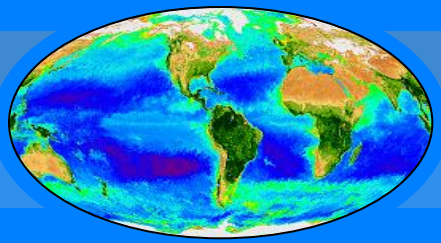


54% of
1955 volume

Changes in Glacier Mass

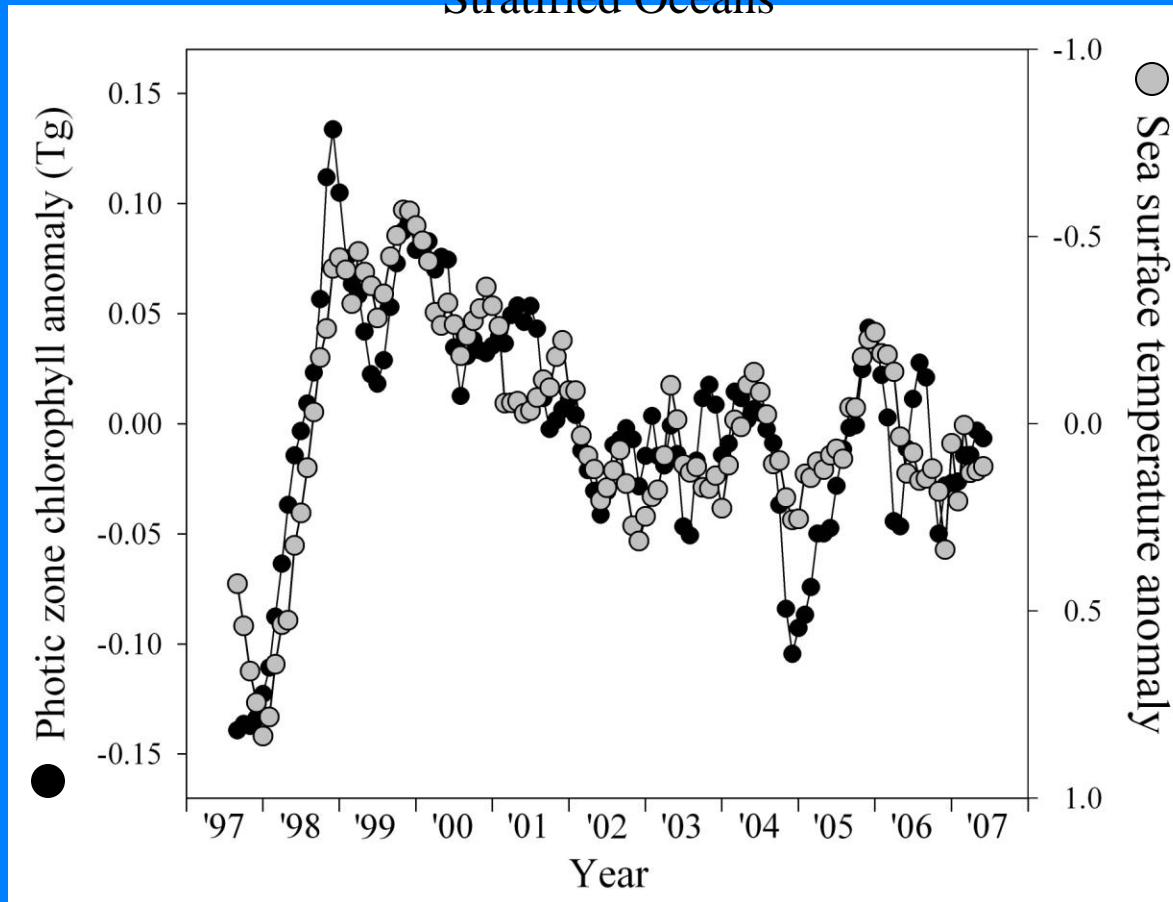






Phytoplankton & Climate

Stratified Oceans



CONCLUSIONS

- THE EARTH IS FUNDAMENTALLY A “BOTTOM UP” SYSTEM IN WHICH MICROBES HAVE ADAPTED OVER (LITERALLY) BILLIONS OF YEARS TO MAINTAIN A QUASI-STEADY STATE
- HUMANS, THROUGH EFFICIENT RESOURCE PLUNDER, WILL MODIFY EARTH’S ATMOSPHERE AND CLIMATE - BUT MICROBES WILL EASILY SURVIVE.
- ANIMALS (INCLUDING HUMANS) AND SOME PLANTS ARE EXTREMELY VULNERABLE TO HUMAN ACTIVITIES - AND MANY SPECIES PROBABLY WILL GO EXTINCT IN THIS CENTURY.